The Beneficial Effects of Motivational Self-Talk on Endurance Performance and Cognitive Function in the Heat

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Abstract

The role of psychological strategies on endurance performance and cognitive function in the heat is unclear. This thesis tested the effects of a two-week motivational self-talk (MST) intervention - specific to heat stress - on endurance capacity and cognitive function in the heat (35°C 50% RH). The study utilized a pre-test / post-test design testing endurance capacity using a time to exhaustion test (TTE) after exercise-induced hyperthermia. Cognitive function (e.g executive function) was tested at baseline in thermoneutral (22°C 30% RH), before (R1) and after the TTE (R2). MST led to a significant improvement (~30%) in TTE and significantly faster completion time with fewer errors made on executive function tasks at baseline and R2, but not in R1, while there were no differences in the control group. Overall, these results indicate that using a top-down regulation strategy consisting of self-contextualized MST can improve physical and cognitive performance in the heat.

Key Words: Motivational Self Talk, Endurance Performance, Executive Function, Exercise Induced Hyperthermia, Mental Skills Training

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ACC	=	anterior cingulate cortex
AI	=	anterior insula
ANT	=	attention network test
BRUMS	=	Brunnel Mood Scale
CFQ	=	Cognitive Failure Questionnaire
CGM	=	Central Governor Model
CNS	=	central nervous system
CO_2	=	carbon dioxide
CON	=	Control
DEC	=	deception
EEG	=	electroencephalogram
EX1	=	exercise 1
FAM	=	familiarization trial
GMLT	=	Groton Maze Learning Task
HR	=	heart rate
IZOF	=	Individual Zone for Optimal Functioning
MAM	=	Maximal Adaptability Model
MD	=	medial dorsal nucleus
MST	=	motivational self-talk
NTS	=	nucleus of the solitary tract
O_2	=	oxygen
R1	=	rest 1
R2	=	rest 2
PPO	=	peak power output
PST	=	psychological skills training
RH	=	relative humidity
RPE	=	ratings of perceived exertion
RPM	=	revolutions per minute
T_{amb}	=	ambient temperature
T_c	=	core temperature
T_{re}	=	rectal temperature
$\overline{T}_{sk}$	=	mean skin temperature
T_{skin}	=	skin temperature
TC	=	thermal comfort
TN	=	thermoneutral
TS	=	thermal sensation
TTE	=	time to exhaustion
USG	=	urine specific gravity
$\dot{V}_E$	=	ventilation
VA	=	voluntary activation
VM_{po}	=	ventral medial nucleus
$\dot{V}O_2$	=	volume of oxygen

$\dot{V}O_{2peak}$ = peak oxygen consumption
W = watts

1 Introduction

Exercising in hot environments is physically and mentally demanding, where laboratory-based studies utilizing fixed-intensity and self-paced exercise protocols show that premature fatigue occurs in the heat (> 30°C) compared to thermoneutral (~22°C) temperatures (Galloway & Maughan, 1997, Tatterson et al., 2000, Schlader et al., 2011). There are multiple triggers for premature fatigue in the heat (Cheung & Sleivert, 2004) which have been attributed to 'central fatigue' through the attainment of a core temperature (T_c) above 40°C (Gonzalez-Alonso et al., 1999), a reduction in voluntary skeletal muscle activation (Tucker et al., 2004, Tucker et al., 2006), an anticipatory or unconscious down-regulation of power output (Marino et al., 2000, Hartley et al., 2012), and a decreased motivation and arousal (Bridge et al., 2003, Nielsen et al., 2001). Out of these factors, research into the psychological impact during exercise in the heat is sparse compared to the physiological literature (Barwood et al., 2008).

Psychological factors such as motivation, drive, and thermal perceptions are proposed to alter before any measurable physiological changes (Kobrick & Johnson, 1991) and are more vulnerable to thermal stress (Hancock & Vasmatizidis, 2003), which may influence both cognitive and physical performance in the heat. Performance in the heat may improve through psychological skills training before entering a thermal environment. For example, it has been shown that four hours of broad-spectrum mental skills training improves the distance covered in a 90 minute running time trial by 1.15 km (8%) in 30°C (Barwood et al., 2008). Furthermore, simple interventions such as deceiving participants with incorrect visual feedback on ambient and core temperatures in the heat, alleviates performance decrements in cycling when compared to no deception (Castle et al., 2012). Combined, these findings suggest that the plasticity of psychological perceptions during thermal stress plays an important role in altering exercise capacity.

There are also declines in cognitive function with progressive rises in T_c due to central changes such as a reduction in global and local neural network efficiency (Qian et al., 2014), which leads to an increased difficulty in neural processing relative to thermoneutral conditions (Hocking et al., 2001, Lui et al., 2013). These functional changes manifest as task-dependent changes in cognitive function. Simple cognitive tasks such as reaction time appear to be less vulnerable and in some cases improve with passive heat stress (Hocking et al., 2001, Gaoua et al., 2011). In contrast, higher order cognitive functions such as executive function, vigilance, visual memory, and planning appear to be decreased with a passive rise in T_c by 1.0°C (Hancock & Warm, 1989, Hocking et al., 2001, Gaoua et al., 2011, Lui et al., 2013). It is believed that these higher order cognitive functions are more vulnerable to heat stress, as there is a neural shift in resources from the executive attention network in the anterior cingulate cortex, to the alerting and orienting networks to maintain simple task performance (Liu et al., 2013). What is not currently known is if psychological skills training could have a beneficial effect on cognitive function in the heat (due to the added neural effort and the limited neural resources available to perform mental tasks when hyperthermic).

Based on pervious research, it is possible that a beneficial psychological skills training intervention that may improve both cognitive and endurance performance is motivational self-talk (MST), which is commonly used in broad-based psychological skills training (Barwood et al., 2006, Thelwell & Greenless, 2001). Motivational self-talk is a multidimensional phenomenon that focuses on an individual's self-addressed verbalizations to re-appraise negative thought patterns with instructional and motivational statements (Hardy, 2006). These statements influence an individual's attention and appraisal process, which lead to a regulation of behavioural performance (Meichenbaum, 1977). In thermoneutral environments, MST is shown to increase endurance capacity by 18% during a time to exhaustion test (Blanchfield et al., 2014), and significantly improve self-paced 10 km time trial time (Barwood et al., 2015). Additionally, qualitative feedback from athletes utilizes MST proposes an improvement confidence, focuses attention, improves concentration, and creates positive moods through active appraisal strategies, which may lead to an improvement in cognitive function (Hardy et al., 2001, Van Raalte et al., 1994, Hatzigeorgiadis et al., 2004, Hatzigeorgiadis et al., 2007, Hatzigeorgiadis et al., 2011). However, to our knowledge, this has yet to be systematically tested and quantified in thermoneutral or hot environments.

A hot environment may be the ideal condition to test if MST affects performance due to the physiological, psychological, and cognitive decrements that occur in the heat. Therefore, the purpose of this thesis is to investigate the effectiveness of MST on exercise and cognitive performance in a hot (35°C 50% RH) environment. It is hypothesized that MST will have a beneficial effect and improve both endurance capacity and cognitive function in the heat due to a top-down regulation of performance. Having introduced the purpose of the study, the following chapter will provide a review of the literature where sections 2.1- 2.4 will focus on how heat stress effects exercise, and neurobiological, cognitive, and neuropsychological function. Sections 2.5-2.6 of the literature review will focus on how and why psychological interventions such as MST can be used to increase exercise and cognitive function. Section 2.7 will provide a possible mechanism linking psychological and physical performance. Following the review of the literature, section 3.0 will present the main hypotheses for the study, section 4.0 will present the methods used, section 5.0 will present the results, and 6.0 will provide the discussion of the findings.

2 Review of the Literature

2.1 Exercise Tolerance in the Heat

Heat exposure impairs multiple physiological systems, causing increases in metabolic rate, increases cardiovascular strain, dehydration, and increases in heat storage and core temperature (T_c), which leads to possible thermoregulatory collapse and a decrease in exercise performance (Galloway & Maughan, 1997, McLellan et al., 2013). Exercise performance in profoundly reduced with high ambient temperatures (T_{amb}) as marathon times are progressively slower (~1-10%) as temperature rises from 5 to 25°C (Ely et al., 2007). Premature fatigue has been attributed to 'central fatigue' through the attainment of a $T_c > 40$°C (Gonzalez-Alonso et al., 1999), an anticipatory or unconscious down-regulation of power output (Marino et al., 2000, Hartley et al., 2012, Hartley et al., 2013), and/ or a reduction in voluntary skeletal muscle activation (Tucker et al., 2004, Tucker et al., 2006) and possibly a decreased motivation (Bridge et al., 2003).

Anecdotal evidence from military records describe that working in tropical climates tends to sap the will and motivation from soldiers to perform routine tasks (Kobrick & Johnson, 1991, Marshall, 1947). Furthermore, soldiers have ceased to function in these hot conditions, even though they were not physically harmed, had adequate food and water, and appropriate clothing was provided (Kobrick & Johnson, 1991). Although there is an acknowledged reduction in this drive, will, and motivation to continue exercising in the heat (Bridge et al., 2003, Nybo & Neilsen, 2001), this psychological component influence on performance is less investigated (Barwood et al., 2008).

The psychological interpretation of thermal stress is a possible factor that could be open for manipulation, as conscious and unconscious psychological factors play an underlying role in behavioural responses to heat stress (Flouris, 2011). A limiting factor of previous studies is that participants know the T_{amb} conditions before the start of exercise (Hartley et al., 2012). Hartley et al. (2012) looked to solve this issue by having participants perform self-paced cycling while maintaining a constant rating of perceived exertion (RPE) of 14 (6-20 scale) for 60 minutes while covertly manipulating environmental conditions every 20 minutes without the participant's prior knowledge from 20°C to 35°C to 20°C. Over the course of the 60 minutes, there were decreases in voluntary power output, however they were not synchronous with abrupt changes in T_{amb}, skin temperature (T_{skin}), sweat rate, heart rate, or changes in heat storage (Hartley et al., 2012, Hartley & Cheung, 2013). Therefore, if changes in T_{amb} or peripheral and central thermal afferent feedback are not the sole cause of change in behaviour, then it could be the perceptions of thermal stress that influences behaviour. If so, manipulating the pre-trial expectation of the thermal environment through psychological means such as deception should overcome decrements of exercise performance in the heat. Castle et al. (2012) tested this hypothesis by having participants perform three randomized 30-minute self-paced cycling time trials, with one being performed in a thermoneutral (TN) (21.8°C) and the others in a hot, humid (HOT) (31.4°C 64% RH) environment while visually providing measures of T_{amb} and T_c to participants. In one of the hot trials, participants were deceived (DEC) into thinking the T_{amb} was cooler (26.0°C 60% RH) and their T_c was 0.3°C lower than it actually was to create a mismatch between the expected and perceived demands of the exercise trial. There was a significant drop in power output and a ~4% decline in distance travelled in the HOT (15.88 ± 2.75 km) compared to the TN (16.63 ± 2.43 km) condition (Castle et al., 2012). However, deception ameliorated this performance decrement, such that there was no performance difference ($p > 0.05$) between the DEC (16.74 ± 2.87 km) and the TN condition (Castle et al., 2012). Furthermore, RPE was lower in the DEC compared to the HOT condition, supporting the plasticity of psychological perceptions of thermal stress and their role in altering exercise capacity and perception of effort. Therefore, evidence suggests that there is an interaction of psycho-physiological mechanisms effecting exercise performance, which can consciously be affected by top-down psychological regulation.

2.2 Cerebral Function

When looking at central psychological factors that can affect performance, it is important to consider what functional changes can occur in the central nervous system (CNS) with hyperthermia. Body and brain temperature increases while exercising in the heat due to an increase in metabolic heat production, an inadequate release of heat from the head, and a decrease (~30%) in heat removal from the jugular vein (Nybo & Nielsen, 2001, Nybo et al., 2002b). Furthermore, there is a decrease in overall brain blood flow due to hypocapnia associated with hyperthermia-induced hyperventilation due to a reduction of atrial carbon dioxide (CO_2) tension (Nybo & Nielsen, 2001, Nybo et al., 2002a, Brothers et al., 2009). This leads to a decrease in cerebral perfusion by 10-30% while exercising in the heat (Nybo et al., 2002a, Nelson et al., 2011). Cerebral metabolism may partially compensate for the decreased blood flow, increasing oxygen (O_2), glucose, and lactate uptake by 7% (Nybo et al., 2002a, Ida & Secher, 2000).

The hyperthermic brain leads to a decrease in arousal, motivation, and neural processing (Nielsen et al., 2001, Nybo & Nielsen, 2001, Bridge et al., 2003, Cheung & Sleivert, 2004, Cheung, 2010). Studies using electroencephalogram (EEG) show a decline in high frequency β-band waves in the prefrontal cortex that is strongly correlated ($r^2 = 0.98$) with progressively rising T_c (Nielsen et al., 2001, Rasmussen, Nybo, & Nielsen, 2004). Brain activity normally shifts from high frequency β-band waves during periods of alertness to increased activity of α-band waves when drowsy, indicating that increases in T_c leads to decreased arousal (Nielsen et al., 2001). Changes in arousal are not due to the changes in cerebral haemodynamics listed above, but rather the increase in T_c (Rasmussen et al., 2004). Even when cerebral blood flow is restored through inhalation of CO_2, which reduces the drive to hyperventilate, arousal level is still reduced as brain temperature rises (Rasmussen et al., 2004). Furthermore, there are functional and topographical changes that occur throughout the brain with hyperthermia (Qian et al., 2013).

Cerebral neural processing can be broken down into a series of global networks (clusters of neuronal networks that are not random) and local networks (smaller clusters of networks with highly efficient information transfer with processing at low cost) (Archard & Bullmore, 2007). Neural networks communicate efficiently by using the shortest path length available through the local and global networks (Archard & Bullmore, 2007). Increases in T_c correlates with reduced global and local network efficiency as neural networks shift to randomized networks in an effort to continue to pass information through the shortest length pathways (Figure 2.1) (Qian et al., 2014). There are decreases in nodal efficiency (how one node connects and transfers information to another node) in the pre-frontal and orbito-frontal cortex, and the somatosensory, limbic, and motor cortices (Qian et al., 2014). These overall topographical and functional changes in the brain could be the cause of a decrease in arousal while exercising in the heat.

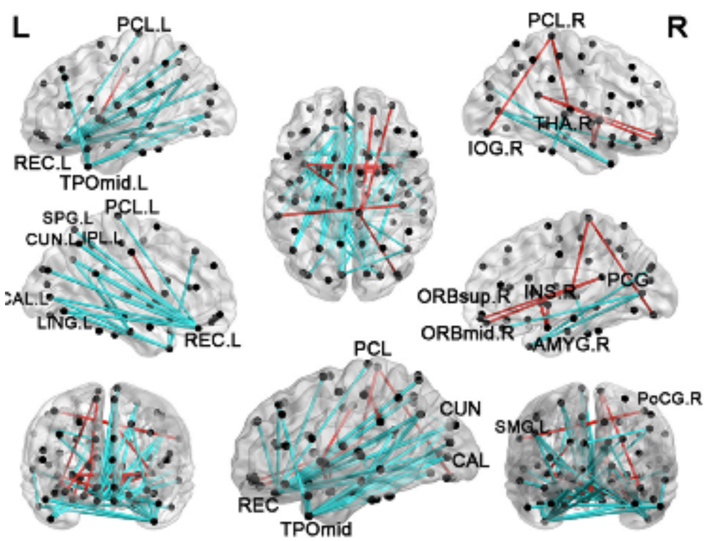

Figure 2-1 - There are significant changes in cerebral functional connectivity between thermoneutral and hyperthermic conditions (increase in T_c by 1.0°C). Blue lines denote significant decreased connections and red line denote significant increased connections with passive hyperthermia. Figure is from Qian et al. (2013).

The changes in the aforementioned cerebral structures trickles down to the rest of the body through a reduction for the capacity of the CNS to voluntarily activate (VA) skeletal muscles independent of the rate of heat storage or local muscle temperature (Morrison et al., 2004, Thomas et al., 2006, Ross et al., 2012). Furthermore, assessing cortical VA through use of transcranial magnetic stimulation shows an ~11% decrease in VA with an increase of T_c by 1.5°C (Ross et al., 2012). These reductions indicate there is a supraspinal involvement in the failure of central drive that starts in the brain and ultimately affects exercise performance (Ross et al., 2012).

Whether through changes in cerebral blood flow, neural processing, or decreases in VA, these hyperthermia-induced CNS factors may directly affect the brain's ability to regulate endurance capacity and perform mental tasks. It is possible that an increase in mental effort due to use of a psychological skill during exercise could lead to an increase in neuronal/ cognitive activity, which in turn would cause a rise in cerebral metabolism, leading to a quicker depletion of neuronal resources (Ide & Secher, 2000). Or there is the potential that a psychological skill could help maintain arousal levels within the brain, and subsequently improve performance.

2.3 Cognitive Function

The functional and topographical changes that occur in the brain with hyperthermia manifests as changes in cognitive performance (Qian et al., 2013, Lui et al, 2013). For example, observations of mineworkers working in extreme hot conditions report higher instances of occupational accidents and mental errors in the heat (Vernon & Warner, 1932, Martinson, 1977). Furthermore, hot temperatures and increases in T_c lead to decrements in cognitive function (Hancock & Vasmatidis, 2003, Pilcher, Nadler, & Busch, 2002, Rasmussen et al., 2004, Gaoua et al., 2011, Hocking et al., 2001).

Cognitive decrements resulting from passive heat exposure are task complexity dependent (Pilcher et al., 2002, Hancock & Vasmatzidis, 2003). Simple cognitive tasks such as reaction time, simple planning tasks, and simple attention tasks are less vulnerable and in some cases improved with passive and active heat stress (> 30°C), with or without rises in T_c as there may be a beneficial arousal enhancement (Racinais et al., 2008, McMorris et al., 2006, Hocking et al., 2001, Simmons et al., 2008, Gaoua et al., 2012, Gaoua et al., 2011, Morison et al., 2012). As T_c increases, tasks like reaction time performance is maintained, but it takes individuals longer to find the correct answer during a task (Gaoua et al., 2011). However, once T_c rises above 38.7°C, reaction time and other simple task performance rapidly decreases (Gaoua et al., 2011). Not all simple cognitive skills are maintained as short-term memory is decreased in extremely hot environments (50°C 50% RH), and time is perceived as going faster (Racinais et al., 2008, Gaoua et al., 2011, Tamm et al., 2014).

Higher order cognitive functions like executive function, vigilance, dual tasking, visual memory, decision-making, and planning are decreased with passive heat exposure (Hancock, 1989, Hocking et al., 2001, Gaoua, 2010, Gaoua et al., 2011, Hancock, Ross, & Szalma, 2007, Lui et al., 2013). Generally, as the task complexity increases, the lower amount of heat stress is needed to perturb cognitive function (Hancock & Vasmatzidis, 2003). For example, it takes participants significantly longer to find the correct answer on a complex planning task in the heat (50°C 30% RH; Response Time: 39.43 ms ±19.34) compared to thermoneutral (24°C 30% RH; Response Time: 23.43 ms ±12.59), while there is no significant ($p > 0.05$) change during simple planning tasks (Gaoua et al., 2012). Since complex cognitive skills are more susceptible to decrements in the heat, interventions should look to improve complex cognitive performance over simple task performance.

There are mixed findings on the effects of exercise and heat stress on cognitive performance. Moderate intensity exercise in thermoneutral environments decreases reaction time, and improves short-term memory and decision-making (Chmura et al., 1998). These trends continue with exercise in the heat, as 90 minutes of prolonged light intensity exercise (40-45% VO_{2max}) has a beneficial effect on information processing, psychomotor vigilance, and executive function in the heat (35-38°C) (Parker et al., 2013). Furthermore, reaction time, short-term memory, speed and accuracy are maintained during pre and post 40 minutes of simulated firefighter activity (60% VO_{2max}) in the heat (35°C) (Zhang et al., 2014). There may actually be a lag time before there is a drop in cognitive performance after exercise, as changes in psychomotor vigilance and short-term memory is not seen until 1 hour after 50 minutes of exercise in the heat (Morley et al., 2011). Conversely, previous studies that found a decrease in cognitive performance with exercise in the heat found it was dehydration that may have caused the decrease in performance (Bandelow et al., 2010, Cian et al., 2002). For example, Cian et al. (2000) found that passive or active dehydration of ~2.8% impaired short-term memory and reaction time. Therefore, care should be given to prevent dehydration of >2% because it may be a confounding variable affecting cognitive function.

2.3.1 Neural Resources

Until recently, it was unknown what the functional underlying mechanisms were for changes in cognitive function due to passive hyperthermia. Studying the cognitive process of attention, which is where an individual selectively concentrates on one aspect of the environment while ignoring other aspects, can tease out changes in brain function leading to a decrease in cognitive performance (Liu et al., 2013). Attention can be divided into 3 distinct neural processing networks: alerting network, orienting network and the executive attention network.

i) The alerting network prepares for a stimulus by establishing and maintaining a state of alertness (Liu et al., 2013). The alerting network is a neural network that resides in the frontal and parietal lobes and in the thalamus and is dependent on norepinephrine to induce alertness (Posner & Petersen, 1990, Coull et al., 1996).

ii) The orienting network selectively attends to cued areas and provides the basis where an individual can direct attention to an area of space, with or without eye movement towards an area of space (Liu et al., 2013). The orienting network is a neural network that resides in the prefrontal cortex and parietal cortex and is modulated by choleric activity in the basal ganglia (Posner & Petersen, 1990).

iii) The executive attention network is involved with decision-making, conflict resolution, inhibiting a response, planning and action (Posner & Petersen, 1990). The executive network is a neural network that resides in the frontal lobe, lateral prefrontal cortex, anterior cingulate cortex (ACC), and dopamine facilitates executive function (Posner & Petersen, 1990, Ko et al., 2009).

The 3 attention networks can be tested and separated using the Attention Network Test (ANT) conducted in an fMRI machine during passive heat stress (Fan et al., 2002, Liu et al., 2013). A 1.0°C increase in T_c through passive hyperthermia (50°C 40% RH) leads to no performance ($p > 0.05$) changes in the alerting and orienting networks, but performance significantly ($p < 0.05$) declines in executive attention network compared to thermoneutral conditions (20°C 40% RH) (Sun et al., 2012, Liu et al., 2013).

Functionally, the alerting network and orienting network have altered activation patterns with hyperthermia, and uses resources from other areas of the brain, including the executive attention network to maintain performance (Figure 2.2) (Liu et al., 2013, Qian et al., 2014, Hocking et al., 2001). The executive attention network performs complex cognitive tasks and, because it uses more neuronal resources, its function is impaired greater compared to the other attention networks (Hocking et al., 2001, Liu et al., 2013). However, hyperthermia decreases the efficiency to resolve conflicts, but does not affect the ability to monitor conflicts in the ACC (Liu et al., 2013). This is an important distinction to note for neural function, as it indicates that information can be processed in the ACC, however the higher order cognitive function is impaired. Therefore, there are more neural resources available to monitor afferent feedback from bodily systems and to selectively attend attention to a cue, while there are less available resources for decision-making and resolving conflicts (Liu et al., 2013). Overall this means that there are limited neural resources available for cognitive processing (Hocking et al., 2001). The brain uses more neural resources in order to maintain the same performance on simple tasks with thermal strain, while higher order cognitive skills like executive function are impaired with thermal stress because neuronal resources are overloaded leading to a decrease in performance. These findings indicate that a psychological skill intervention would need to be mindful of neuronal resources.

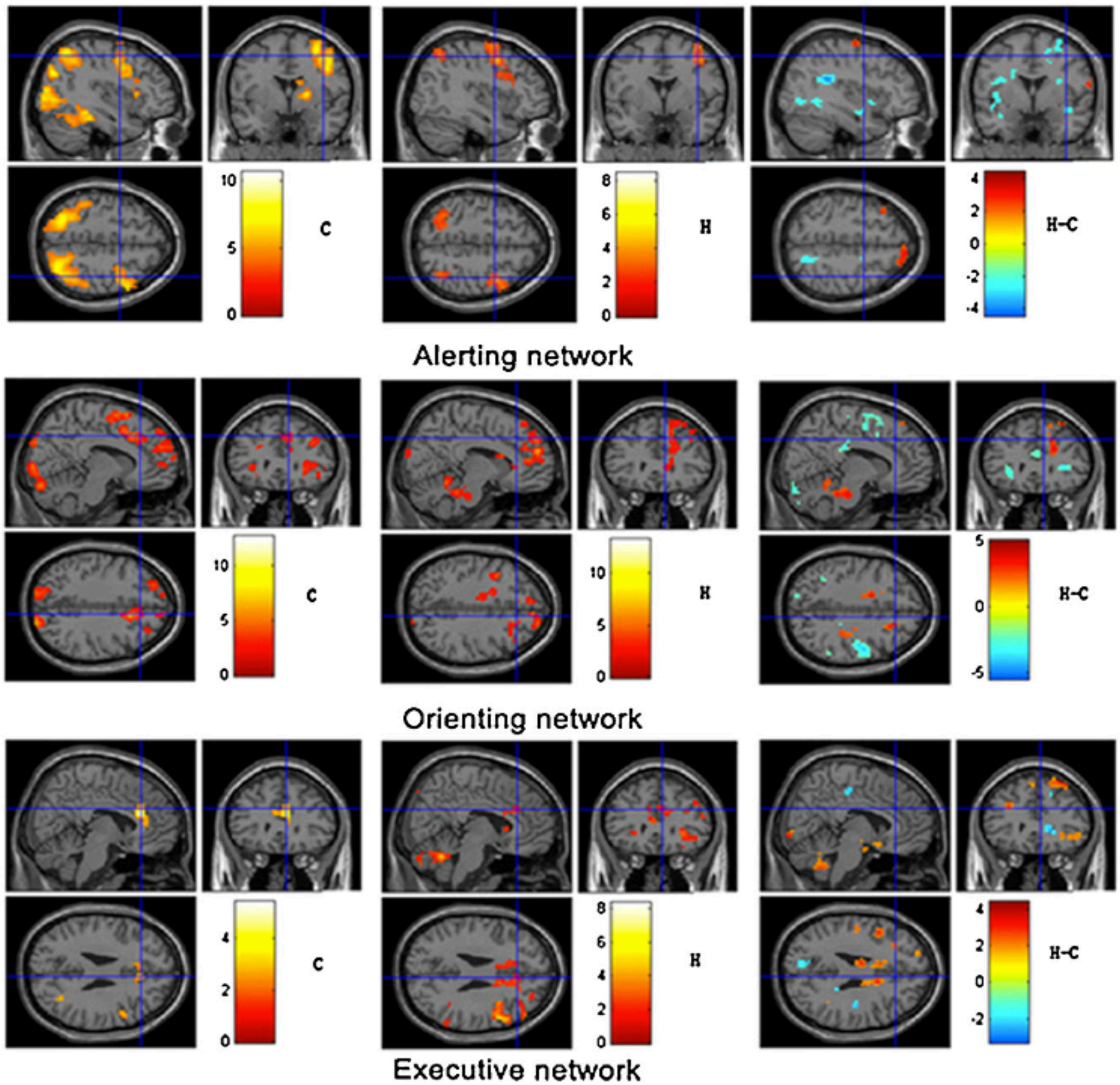

Fig. 5. fMRI results for the three attentional networks. The cross-section view of activations of the alerting network shows the premotor cortex activations of the alerting effect in control group (C), hyperthemia group (H), and the compared results of the two groups (H–C). The cross-section view of the orienting network shows frontal activation in the control group (C), hyperthemia group (H), and the compared results of the two groups (H–C). The cross-section view of the conflict network shows ACC and dorsolateral prefrontal cortex activation in the control group (C), hyperthemia group (H), and the compared results of the two groups (H–C).

Figure 2-2- Results from Lui et al. (2013). Figure depicts the changes in the three attentional networks: alerting, orienting, and execution function using fMRI during thermoneutral, hyperthermia and a comparison between both groups.

2.3.2 *Arousal Hypothesis*

Task performance on cognitive tasks in the heat has been described by arousal theory, which argues an inverted U-relationship (known as the Yerkes-Dodson law) exists between cognitive performance and arousal regulation (Yerkes & Dodson, 1908). As T_{amb}, T_c, and T_{skin} rises, so does an individual's arousal level, until performance is maximized at an optimal state of arousal (Wilkinson et al., 1964, Hocking et al., 2001). Performance will gradually decline as arousal level continues to increase past the optimal arousal level (Arent & Landers, 2003). Extending arousal theory, Hanin (1978, 1980) proposed an ideographic framework called the Individual Zone for Optimal Functioning (IZOF), which states that an optimal performance state is one with the best internal conditions (e.g. emotions, arousal). This optimal zone of functioning will lead to a complete involvement in a task and result in the best possible performance. For example, an individual may perform optimally while having positive emotions and low arousal, while another individual can use negative emotions and a high state of arousal to perform optimally (Tennenbaum et al., 2008). The Inverted U-Hypothesis and the IZOF have a limited ability to apply outside of a theoretical framework because it is highly descriptive, but cannot be experimentally quantified (Hancock & Warm, 1989, Hancock & Vasmatzidis, 2003).

Hancock & Warm (1989) proposed the Maximal Adaptability Model (MAM) to better explain the changes in cognitive performance due to heat stress through the changes in psychological and physiological changes that occur in the heat (Figure 2.3). In this model, stressors range from hypostress (e.g. boredom) to hyperstress (e.g. hyperthermia). In the middle of these two extremes is the 'normative zone', where performance level is near optimal because cognitive adjustments to the task demands are easily accomplished (Hancock & Vasmatizidis, 2003). In the normative zone, minor levels of stress inputs are readily adapted to, and do not disturb steady-state functioning or reflect any changes in behaviour or cognitive performance (Hancock & Warm, 1989). Therefore, as T_c, T_{amb}, T_{skin}, duration in environment or complexity of task increases, arousal levels increase and cognitive resources efficiently shift so that cognitive performance is maintained or enhanced due to an optimal state of arousal (Hancock & Vasmatizidis, 2003, Lui et al., 2013, Hocking et al., 2001). With these changes, there is a maximal zone of adaptability, where task performance is unaffected (Hancock & Warm, 1989). Eventually the increased level of stress will extend past this zone and deplete neural resources, which progressively declines cognitive performance (Hancock & Vasmatizidis, 2003).

The strength of the MAM is that is has both a physiological and psychological maximal zone of adaptability when exposed to stressors. The physiological zone of adaptability is when physiological responses move outside of homeostasis (solid lines – Figure 2-3) where there is an increased risk of heat related illnesses or death (Hancock & Vasmatizidis, 2003). The psychological zone of maximal adaptability is more vulnerable than physiological changes. Initially when faced with environmental stress, an individual can effectively shift attention resources to the task through psychological strategies to maintain performance (Hancock & Vasmatizidis, 2003). At high levels of stress, there will be a decrease in neuronal resources available or the ability to focus attention on the task, which leads to a progressive decline in cognitive performance (dashed line -- Figure 2-3) (Hancock & Warm, 1989, Chase et al., 2005).

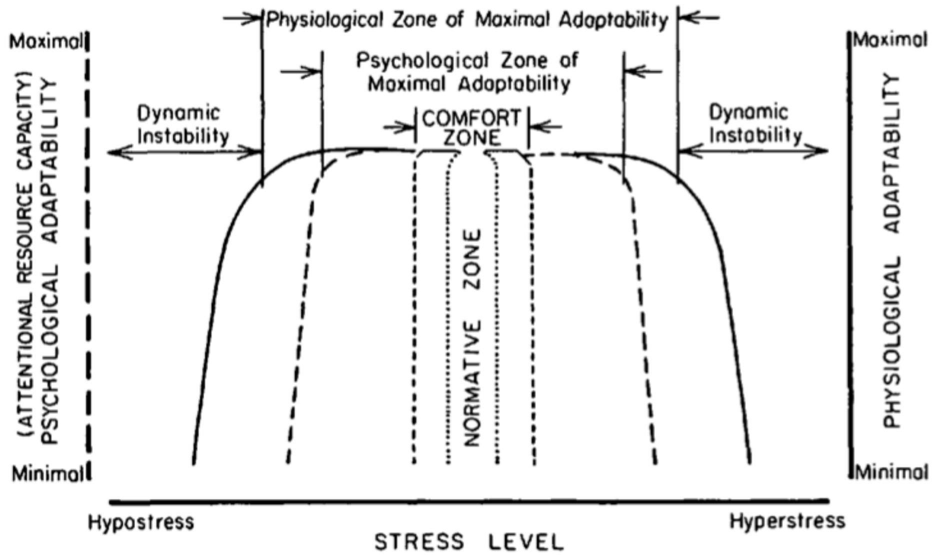

Figure 2-3- The Maximal Adaptability Model includes both physiological (solid lines) and psychological (dashed lines) adaptive capability. There is a normative zone where environmental stress is insufficient to cause degradation in performance. Within the psychological zones of adaptability negative feedback dominates. Outside of these zones is dynamic instability that will eventually lead to functional failure. Figure is from Hancock & Warm (1989).

A limitation of arousal theory, along with IZOF, and the MAM, is that the impact of psychological factors has not yet been quantified. All three models point to a common factor, that there is a psychological influence on cognitive performance, however the role of psychological factors are often inferred as a last resort to explain the individual variability in responses that cannot be accounted for based on thermal factors. One method that could remedy this issue is to use a psychological skill training intervention that is tailored to the physical and cognitive demands of exercising and performing cognitive testing in the heat. Psychological skills may attenuate or improve cognitive performance in the heat due to arousal regulation. Theoretically, by using a top-down regulation of psychological skills training, cognitive decrements may be attenuated by staying in the optimal zone for longer. Or the use of a psychological skill could overload neuronal resources leading to a quicker decrease in cognitive function.

2.4 Perceptual Measures

2.4.1 Ratings of Perceived Exertion and Heat Stress

Ekkekakis (2003) suggests that two modes of processing interact with each other to determine perception of effort of exercise: 1) a bottom-up, feed forward interoceptive system incorporating different afferent cues based on exercise relevant physiological changes and 2) a top-down, cognitive system that is involved in appraising the meaning of exercise, self-perceptions, past experience, goals, and the social context of exercise. Therefore, the conscious perception of effort is derived from sensory input from the cardiovascular, respiratory, and musculoskeletal system and an affective appraisal of exercise (Crewe et al., 2008, Flouris & Cheung, 2009).

RPE linearly rises with increasing $T_{c,}$ time and intensity of exercise in the heat (Gonzalez-Alonso et al., 1999, Nielsen et al., 2001, Nybo & Nielsen, 2001). For example, time to exhaustions (TTE) is negatively correlated (r = 0.83) with the rate of rise in RPE during fixed intensity exercise in cold (15°C 50% RH) and hot (35°C 50% RH) environments (Crewe et al., 2008). RPE may be determined at the beginning of exercise as part of a feed forward mechanism (Noakes, 2004, Noakes et al., 2005, Baden et al., 2005, Tucker, 2009). For example, at fixed-intensity exercise (e.g. 75% VO_{2max}), an unexpected increase in duration of exercise (e.g. from 10 min to 20 min) significantly ($p < 0.05$) increases RPE compared to when the total exercise duration in known before exercise (e.g. 20 min) (Baden et al., 2005). On the other hand, when exercise duration is unknown, RPE is significantly lower along with oxygen consumption compared to when exercise duration is known (Baden et al., 2005). Overall this indicates that RPE is scaled in a teleoanticipation manner before exercise begins, such that perception of effort and exercise performance is centrally regulated in the brain (Swart et al., 2009, Noakes et al., 2005).

The Central Governor Model (CGM) is a model that describes fatigue and RPE as a result of a subconscious regulation to avoid catastrophic physiological failure regulated by a complex and intelligent system (Noakes et al., 2004, St Claire Gibson & Noakes, 2004, Noakes et al., 2005). The brain processes afferent feedback signals containing thermal, metabolic, and kinetic information from the body, which will regulate an appropriate amount of neural drive to the exercising muscle mass via efferent pathways (Ulmer, 1996). A fundamental component of the CGM is that there is an anticipatory/ feedback component (termed teleoanticipation) (Figure 2.4.1) before exercise that takes into account physiological components (e.g., T_{skin}, T_c, T_{amb}, glucose) and psychological components (e.g., duration, motivation, distance completed, previous experience) to create a mental template to give enough effort to complete the task and avoid catastrophic failure (Tucker, 2009). Therefore, the CGM argues that fatigue itself occurs in the heat as a result of hyperthermia, and subconscious modification in central activation as a protective mechanism to prevent heat illness and/or death (Tucker et al., 2006).

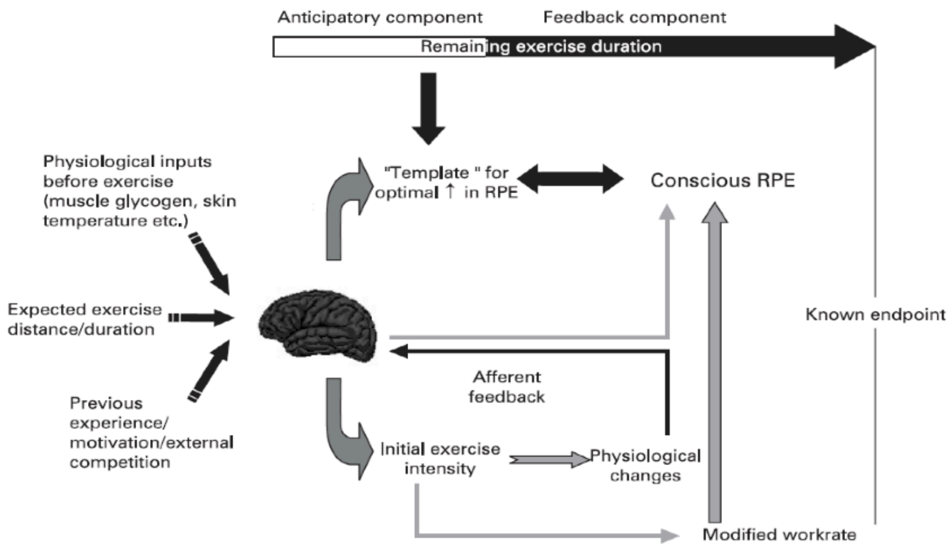

Figure 2.4.1- Schematic overview of the anticipatory/feedback component of the CGM. Figure from Tucker (2009).

The CGM has been criticized due to the lack of testable parameters that currently exist to prove or disprove the model (Cheung, 2009). Also this model focuses solely on subconscious regulation of behaviour, even though conscious regulation also plays a role (Marcora, 2007, Castle et al., 2012). Furthermore, although the CGM is purported to be located in the brain, yet there are no proposed neural systems associated with this model. Due to the subconscious nature of the CGM, it cannot fully explain how a psychological skill intervention could improve exercise performance. However, it could help with the anticipatory component of exercise by affecting the pre-exercise mental template and help participants to psychologically push themselves harder to improve exercise performance.

2.4.2 *Mood and Heat Stress*

Exercising in the heat is associated with a negative mood state, however changes in mood states are rarely investigated (Kobrick & Johnson, 1991, Lane et al., 2004). Passively, McMorris et al. (2006) measured changes in mood using the Profile of Mood States Questionnaire that measures fatigue, vigor, anger, depression, and tension, pre and post a two-hour passive trial in a hot environment (36°C, 75% RH). There were significant decreases in vigor, and significant increases in fatigue, while there were no statistical differences in anger, tension, and depression (McMorris et al., 2006). This lack of change could have occurred due to the passive nature of the heat stress, as military exercise coupled with sleep loss and hypohydration leads to significant rises in depression, tension and anger (Lieberman et al., 2005). There is limited evidence for changes in mood state during exercise in the heat. However, progressive decreases in mood, especially increases in depression, tension, and anger are predicted to occur as these changes occur after high intensity exercise (Lane et al., 2004, Beedie, Terry, & Lane, 2000). Depression may be the most important mood variable to monitor because of its de-motivating nature, which leads to a decrease in exercise performance (Terry & Lane, 2004).

Monitoring mood state during exercise in the heat is an important variable to consider because it can predict athletic performance (Beedie et al., 2000), reflects changes in the environment (Bahrke & Shukitt-Hale, 1993), and reflects an individual's perceived ability to cope with adverse environments (Acevedo & Ekkakakis, 2001). Lane et al. (2004) proposed a model that recommends monitoring mood states in extreme adverse environments (Figure 2.5), where a decline in mood will reduce effort, which in turn reduces the likelihood of them achieving their goal, and leads to a decrease in endurance performance (Lane et al., 2004, Acevedo & Ekkekakis, 2001). Therefore, it is possible that a psychological skill intervention may help maintain mood state throughout exercise in the heat, which may positively affect exercise performance.

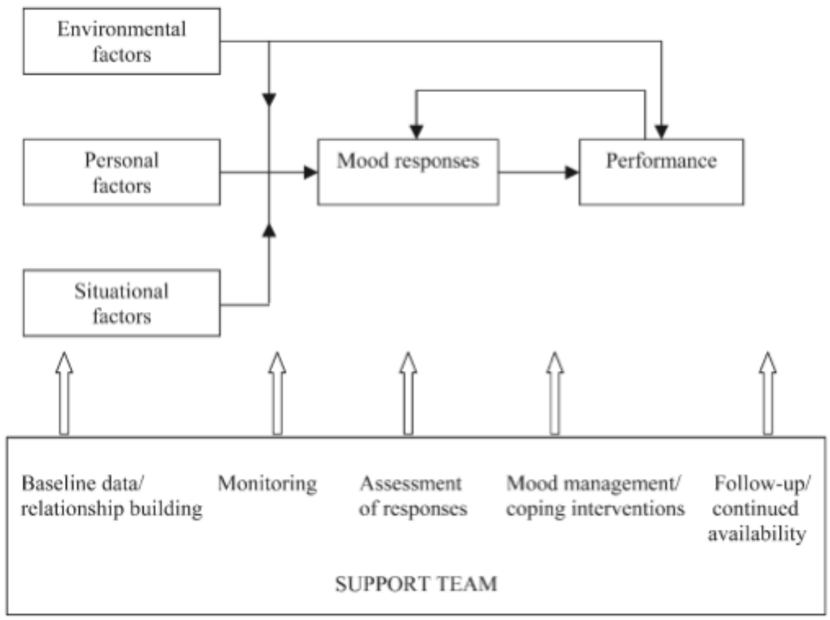

Figure 2-4- Lane et al. (2004) model for mood monitoring for athletic performance in extreme conditions.

2.5 Psychological Intervention Strategies

The study of psychological interventions in extreme environments is relatively new, which is perplexing as these environments are physically, psychologically, and cognitively demanding. Although new, a growing body of research suggests that psychological training may supplement physical practice and enhance skill execution and performance in demanding adverse environments (Barwood et al., 2006, Barwood et al., 2008). Broad-spectrum psychological skills training (PST) which includes: motivational self-talk (MST), arousal regulation, imagery, and goal setting aims to maximize conscious control over the behavioural, cognitive, and physiological responses to physical challenges (Bull, 1989). PST has been shown to be effective in improving skilled movement execution (Short et al., 2002); closed skills (Hatzigeorgiadis, Theodorakis, & Zourbanos, 2004); improving performance and consistency in sports such as soccer (Thelwell et al., 2006), cricket (Thelwell & Maynard, 2003) and golf (Thomas & Fogarity, 1997); and increases performance in thermally stressful environments (Barwood et al., 2006, Barwood et al., 2008).

Barwood et al. (2006) were the first to test the effects of PST in an adverse environment by testing the effects of 4 hours of PST on breath-holding time in cold-water (11°C). Responses to submersion in cold-water is typically followed by an autonomic inspiratory gasp known as the cold-shock response which greatly reduces breath-holding time and increases the risk of drowning (Barwood et al., 2006). In the experiment, PST significantly increased breath-holding time by 80% (Trial 1: 24.66 ± 14.60 s versus Trial 2: 44.25 ± 16.31 s), while there were no improvements in breath-holding time without PST (Trial 1: 24.01 ± 6.72 s, versus Trial 2: 21.34 ± 16.31 s) (Barwood et al., 2006). These results indicate that a conscious motivation can override autonomic responses such as the overwhelming drive to breathe due to the cold-shock response. This initial study was followed up by testing the effects of PST on running performance during a 90-minute time trial in the heat (30°C, 40% RH) (Barwood et al., 2008). Before implementing PST, participants were matched for their running performance, so any improvement in performance would be due to a conscious top-down regulation of performance. The group that received PST improved distanced travelled in the 90-minute time trial by 1.15 km (~8%), while there were no improvements in the control group (Barwood et al., 2008). Results from the study also indicate that mental skills training were effective when exercise was difficult because performance differences were seen in the last quarter of the time trial (Figure 2.6) (Barwood et al., 2008). Out of the four mental skill-training strategies, MST has become a popular technique for increasing endurance exercise performance in thermoneutral environments (Blanchfield et al., 2014, Barwood et al., 2014). Furthermore, participants rated MST as the most used and beneficial mental skill for performance in the heat (Barwood et al., 2008). The following sections provide a detailed overview of MST and how it improves performance.

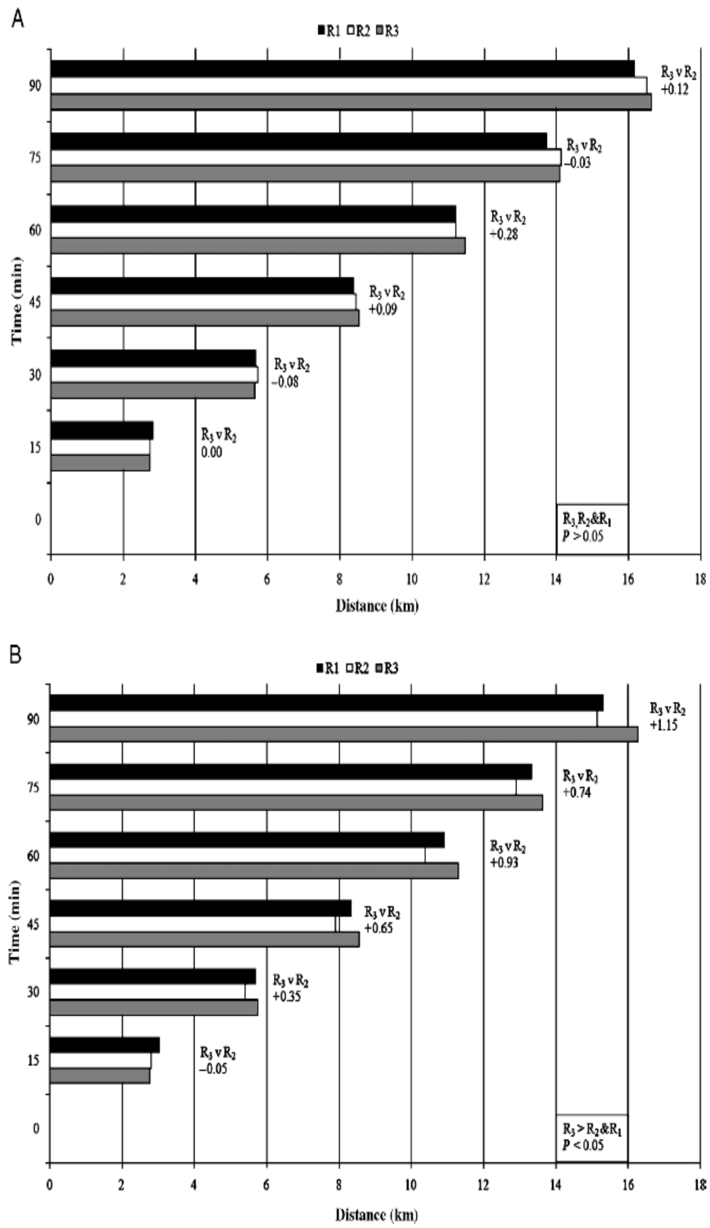

Figure 2-5 - Average distance run in three 90-minute running trials in the heat. Psychological Skills Training was given in between runs 2 and 3 (B) or was not given at all (A). PST training showed to be beneficial than no training as the time trial progressed and exercise became more difficult. Figure is from Barwood et al. (2008).

2.5.1 Motivational Self-Talk

Self-talk is broadly defined as the inner dialogue in which an individual interprets inner feelings, evaluation, and perceptions and gives him/herself instructions and motivations (Morin, 2005). For an improvement in exercise performance, self-talk is considered a multidimensional phenomenon that focuses on the individual's self-addressed verbalizations that re-appraise negative thought patterns into instructional and motivational statements (Hardy, 2006). These statements influence an individual's attention and appraisal process, which lead to a regulation of behavioural performance (Meichenbaum, 1977). MST includes cues aiming at 'psyching up' (e.g. 'lets go'), maximizing effort (e.g. 'keep pushing', 'give it all you got'), building confidence (e.g. 'I can do it') and creating positive moods (e.g. "I feel good") (Hatzigeorgiadis et al., 2011). Instructional self-talk statements include cue aiming and focusing or directing attention (e.g. 'Focus on the net'), technique, strategy, and kinesthetic attributes of a skill (e.g. 'Smooth motion') (Hatzigeorgiadis et al., 2011).

The efficacy of a self-talk intervention is dependent on the type of task. Fine motor skills tend to improve more with instructional self-talk, while gross motor tasks such as aerobic exercise and those requiring strength improve with MST (Hatzigeorgiadis et al., 2011). For example, Hatzigeorgiadis et al. (2004) found MST and instructional self-talk improved accuracy of shots, but only MST improved shot power in water polo players (Hatzigeorgiadis et al., 2004). Post experiment questionnaires revealed that self-talk increased attention to the task and prevented the development of negative thoughts and the occurrence of interfering thoughts (Hatzigeorgiadis et al., 2004).

One of the goals of MST is actively rephrasing negative statements (e.g. 'I suck') to positive and motivational statements (e.g. 'I can do it'). Negative self-talk statements are more prevalent during failure and during unsuccessful performances, which is associated with an increase in anxiety (Conroy & Metzler, 2004). Although some athletes can use negative self-talk statements to help motivate performance, there is a trend that this reduces performance (Hardy et al., 2001, Gammage et al., 2001). Caution should be used when implementing MST in order to not suppress negative thought patterns but to rephrase them and actively use more motivational self-talk statements. Paradoxically, having a cognitive strategy to empty the mind of a thought causes that thought to sample more frequently (Wegner et al., 1990). Suppression causes a 'rebound effect' where a person will continue to reference a thought to gauge if they are successful in their goal of not thinking of a specific thought (Cioffi & Holloway, 1993). This process includes negative thought patterns because to test how successful you are at not using negative statements, you will have to mentally scan for possible negative statements, thus drawing more attention to the negative thoughts you are avoiding. Furthermore, suppressing a thought is cognitively demanding over time and overloads available neural resources (Cioffi & Holloway, 1993). Therefore when implementing self-talk training, the focus should be on actively re-phrasing negative thoughts as opposed to suppressing them.

2.5.2 The Use of Motivational Self-Talk

Hardy et al. (2001) proposed a model for self-talk usage in athletes (Figure 2.7), which uses MST for the purposes of: i) mastery; ii) arousal regulation, and; iii) drive. Qualitative and questionnaire based studies found athletes use self-talk strategies for mastery to increase concentration, mental readiness, and focus on the task at hand (Van

Raalte et al., 1994, Hardy et al., 2001, Hardy et al., 2005). The use of self-talk significantly decreases the amount of interfering and attention towards inappropriate thoughts, which helps focus on the task at hand (Hatzigeorgiadis et al., 2007). However, the mastery component of self-talk is less frequent when coping with the difficult demands of exercise, and used for fine motor tasks (Hardy et al., 2001).

MST is also used for arousal regulation in order to help ‘psych up’ before exercise, to help relax, and find an optimal zone of arousal (Hardy et al., 2001). Athletes report an increased use of self-talk before and during a competition and during practice as a method to focus on the event (Hardy et al., 2001). The use of self-talk can be tailored to the situation depending on the individual’s arousal and goals, and is shown to be beneficial in reducing anxiety and fear (Conroy & Metzier, 2004; Hatzigeorgiadis et al., 2009). For example, if feeling anxious about an important match, an athlete can use self-talk to manage anxiety to maintain an optimal arousal level (e.g. ‘clear your head and focus on the task at hand’) (Hardy et al., 2001).

The final component is that athletes use MST to increase drive and to keep motivated while training or during a game to push themselves harder (Hardy et al., 2001). During practice, self-talk is used for encouragement to stay focused and work toward a training goal (Hardy et al., 2001). While in competition situations, it is used to focus on the goal of the match and keep focused until the end of the competition (Hardy et al., 2001). The drive function is the most general function of self-talk but keeps the person in a mindset to work towards a goal.

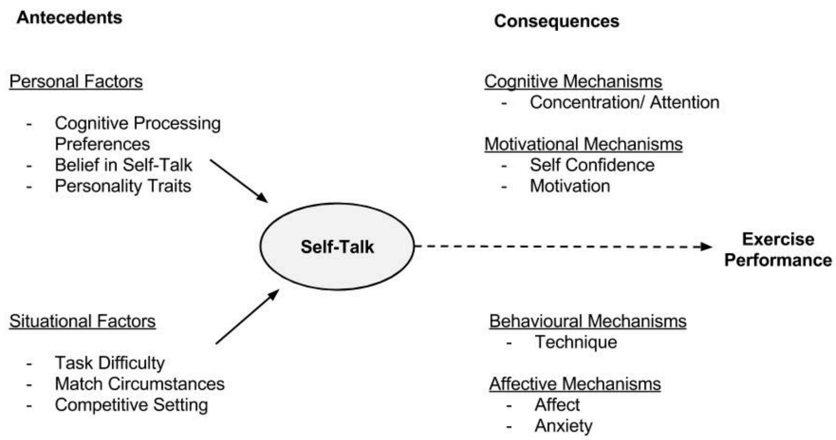

Figure 2-6- Hardy et al. (2008) conceptual framework for how self-talk affects exercise performance.

2.5.3 MST on Endurance Performance

Self-talk interventions have predominately been used in combination with broad-spectrum psychological skills training on endurance performance (Barwood et al., 2008, Thelwell & Greenless, 2001). There is limited evidence, but recent studies have shown that in isolation, MST has a profound effect on endurance exercise (Hamilton, Scott, & MacDougall, 2007, Weinberg, Miller, & Horn, 2012). Blanchfield et al. (2013) was the first study to test an applied MST intervention on endurance performance. The study implemented a repeated measures pretest-post test design comparing a TTE test at 80% of peak power output on a cycle ergometer. Participants either received two weeks of MST training versus no training between Test 1 and Test 2 (Blanchfield et al., 2014). MST training significantly improved tolerance time by 18% (Test 1: 637 ± 210 s Test 2: 750 ±

295 s), while there were no improvements in the control group that received no intervention (Test 1: 486 ± 157 s Test 2: 474 ± 169 s). One criticism of this intervention is the experimenters did not spend the same amount of time with the control group because they received no training, so performance increases could be due to social facilitation with experimenters (Barwood et al., 2015). To remedy this issue, Barwood et al. (2015) tested the effects of MST versus a sham 'Neutral' self-talk intervention on 10 km time trial cycling time. Neutral self talk was given in a similar workbook fashion as MST, but instead of teaching participants to frame negative thoughts as motivational, they are framed as neutral thoughts (e.g. 'My favourite colour is green') (Barwood et al., 2015). Time trial performance time was significantly improved with MST but not neutral self-talk, where statistical differences ($p < 0.05$) occurred from 6 km onwards in the time trial as exercise became more difficult (Figure 2.8) (Barwood et al., 2015). This finding supports the early self reported finding that self-talk is most prevalently used towards the end of a workout when motivational drive is at its most necessary because the desire to terminate exercise is increased (Gammage, Hardy, & Hall, 2001). MST may also influence RPE during endurance exercise; Blanchfield et al. (2013) found that RPE was lower at 50% isotime with MST compared to no intervention. However, Barwood et al. (2015) did not find a significant difference in RPE between neutral and MST even though the MST group cycled an average of 30 Watts (W) more compared to the previous trial.

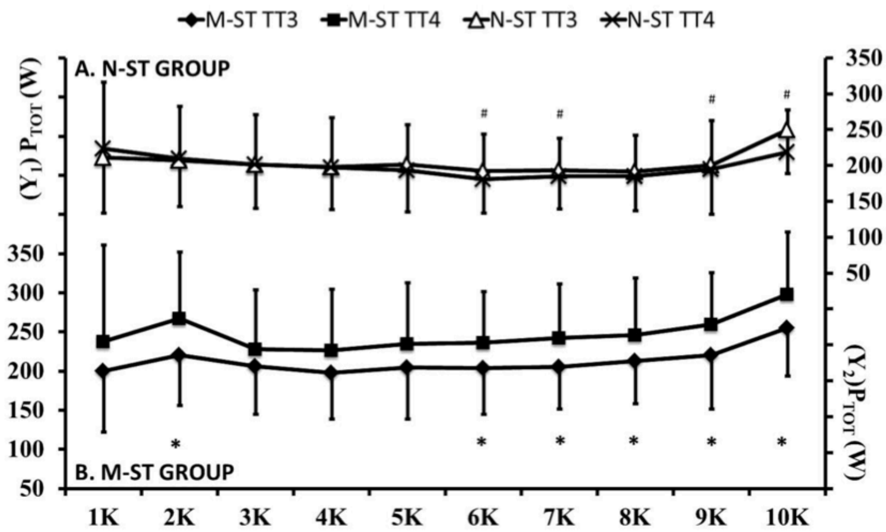

Figure 2-7- Results from Barwood et al. (2015) comparing neutral self talk (N-ST) compared to motivation self talk (MST) on a 10 km time trial. MST performed significantly ($p < .05$) than N-ST with performance data between the two groups occurring from the 6 km mark onwards.

The Psychobiological Model of Endurance Performance, based off the Motivational Intensity Theory, is a possible model for how MST could improve endurance exercise (Brehm & Self, 1989, Marcora et al., 2008, Wright, 2008). This model views exhaustion as a form of task engagement, rather than task failure, where participants decide to ‘give up’ because the effort required to continue exercising exceeds the initial effort they are willing to exert on the task (e.g. potential motivation), or else effort is so high that it exceeds their perceived ability to continue with the task (Marcora & Stiano, 2010). This model predicts that any physiological or psychological factor that affects the conscious perception of effort will influence endurance performance (Marcora et al., 2009, Marcora & Stiano, 2010). Interventions that increase RPE such as mental fatigue, sleep deprivation, and heat stress significantly decrease endurance performance (Marcora et al., 2009, Martin, 1989, Leiberman et al., 2005). On the other hand, interventions that lower RPE - such as MST or carbohydrate rinsing - improve endurance exercise performance (Blanchfield et al., 2014, Chambers, Bridge, & Jones, 2009). This model provides a basis for how MST could psychologically improve endurance performance because MST can motivate participants or increase confidence of their perceived ability to push themselves further. Also, participants will be more motivated and be engaged in the task longer. This benefit may also extend into cognitive testing, where participants will be more engaged during cognitive tests, which could lead to an improvement in performance compared to no psychological intervention.

The efficacy of this model is limited because changes in RPE may not always be evident between experimental trials. This may occur because the same amount of muscle, chemical, mechanical, cardiovascular and thermal afferent feedback occurs between trials is perceptually evaluated, so it's unlikely that a psychological intervention can override the processing of this afferent feedback (Ulmer, 1996, Marcora, 2009). This is because RPE lacks a true affective component because the scale uses descriptors of "light/easy" and "heavy/hard" that describe physical workload rather than hedonic terminology like "pleasant/unpleasant" or "comfortable/uncomfortable" (Cabanac, 2006, Marcora, 2009, Marcora et al., 2009). Therefore affective changes may occur during exercise that may be captured when using the RPE scale. This model is also quite broad, and much like the CGM model, does not provide a neurological basis for how motivation could improve performance.

2.5.4 MST on Cognitive Function

The cognitive mechanisms and effects of self-talk on cognitive ability are relatively unknown, due to the descriptive nature of self-talk studies (Hardy et al., 2008). It has been proposed that self-talk works by improving concentration and increases attention towards the task in order to improve skill performance (Landin, 1994, Hatzigeorgiadis et al., 2004). However, these findings have yet to be systematically tested, as there are no studies testing MST on cognitive function. Furthermore, there has yet to be a study to test the affect of psychological skills training on cognitive function in the before or after exercise in the heat.

2.6 Interoception

Interoception is the sense of the entire physiological condition of the body and how afferent signals can affect awareness of behaviour directly or indirectly. Interoception occurs along the lamina I spino-thalamic pathway (Figure 2.9) (Craig, 2002, Craig, 2009). This is a homeostatic afferent pathway that conveys signals from small-diameter (Aδ and C) primary afferents, which innervate all tissues in the body, and travels to the lamina I in the superficial spinal dorsal horn (Craig, 2002, Craig, 2003). The primary afferent fibers conduct sympathetic physiological conditions including the thermal, mechanical, chemical, metabolic, and endocrine status of viscera, skin, muscle, joints and teeth (Craig, 2002, Craig, 2003).

The second component of this pathway is the nucleus of the solitary tract (NTS), a white bundle of nerve fibers that receive parasympathetic afferent signals from the vagal and glossopharyngeal nerves. The NTS contributes significantly to autonomic function and receives input for taste, chemoreceptor and mechanoreceptor input from the cardio-respiratory system and gastrointestinal tract, where afferent signals are organized viscerotopically (King et al., 1999). This sympathetic lamina I and parasympathetic NTS pathways underlies perceived feelings such as cool, warm, itch, first (pricking) pain, second (burning) pain, muscle burn, hunger, joint pain, thirst, and nausea (Craig, 2010). The ascending lateral spino-thalamic tract projects on to two sides of the contralateral thalamus: the posterior part of the ventral medial nucleus (VM_{po}) and the ventral caudal part of the medial dorsal nucleus (MD). The VM_{po} projects topographically to the mid/ anterior insula (AI) in the insular cortex (IC) (Craig et al., 1994). The MD projects onto the anterior cingulate cortex (Craig, 2002). These two paralimbic structures (AI + ACC) play an important role in behavioural responses to maintain homeostasis.

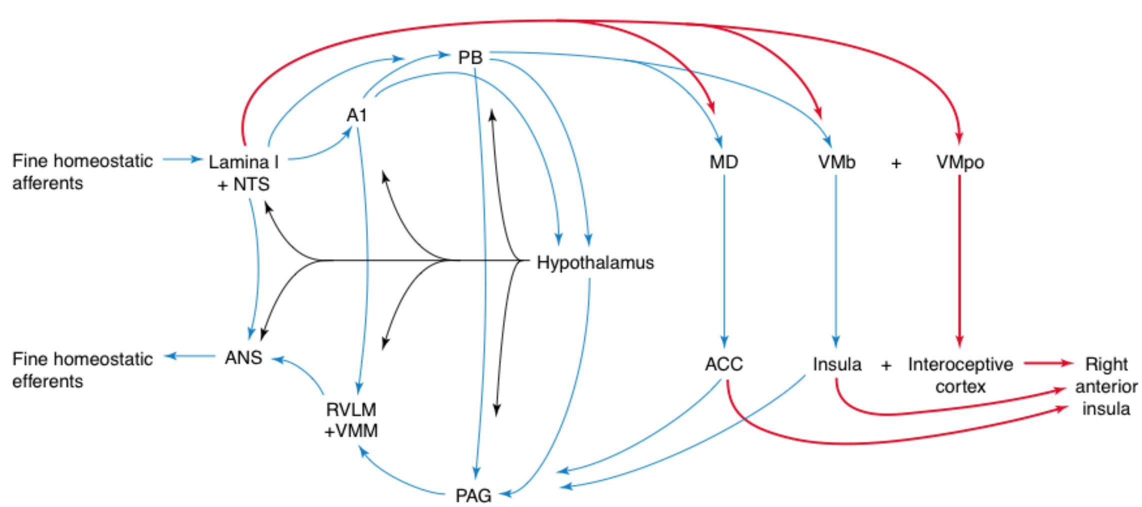

Figure 2-8 - Organizational map of the lamina I spino-thalamic pathway. The afferent pathway is in the top row and the efferent pathway is on the bottom row. The black lines indicate modulation from the hypothalamus. The red lines indicate direct pathways to the insula and anterior cingulate cortex to reflect the physiological condition of the body. The blue lines represent the spino-thalamic path in non-human primates. Figure is from Craig (2003).

The ACC is the limbic sensory cortex that is responsible for numerous higher order cognitive processes such as: motivations, affective appraisal of stimuli, risk/reward determination, decision-making, and executive function (Craig, 2002, Posner & Petersen, 1990). The ACC is modulated through dopamine and is the motivational center in the brain. Increasing dopamine levels with pharmaceutical drugs like methylphenidate significantly improves exercise performance and heat tolerance because it acts directly on the ACC (Liu et al., 2013, Roelands & Meeusen, 2010, Bridge et al., 2003). During exercise the ACC uses peripheral somatosensory input to determine the conscious interpretation of effort (Williamson et al., 2006, Green & Patterson, 2008). ACC activation rises with increases in exercise workload and intensity, which leads to a higher RPE (Fontes et al., 2013, Williamson et al., 2006, Thornton et al., 2001, Williamson et al., 2002). Non-pharmaceutical manipulations of the ACC can affect performance, as mentally fatiguing the ACC through the AX-continuous performance cognitive task decreases TTE at 80% PPO by 16% (Marcora et al., 2009). With hyperthermia of 1.5°C, there is an associated shift in neuronal resources from the ACC which could be a possible neurobiological mechanism for why there is a decreased drive and motivation to exercise in the heat (Lui et al., 2013).

The IC is the limbic motor cortex involved in the integration of sensory and visceral information (Craig, 2002). The AI provides the subjective feelings and awareness of one's self and physical state (Singer et al., 2004). The right and left AI possess reciprocal connectivity to subcortical structures like the lateral hypothalamus, ventrolateral medulla and NTS, which regulate the cardiovascular system during rest and exercise through the vagus nerve (Williamson et al., 1999).

The insular cortex is activated during maximal exercise and increased activation is correlated with an increase in exercise intensity (Williamson et al., 1997, Williamson et al., 1999). The insular cortex does not rely on mechanical and metabolic afferent feedback from the working limbs, as the insular cortex is not activated during passive cycling (tandem ergometer where one partner actively pedals so the other partners limbs are moving without active participation) (Williamson et al., 1997).

The ACC and the IC can function in concert or independently to interpret sensory input and elicit appropriate autonomic adjustments. The AI and ACC simultaneously generate a feeling and an affective motivation of the autonomic afferent signals to complete the interoception pathway (Damansio et al., 2000). The activation of the ACC is related to motivation, and activation of the insula is associated with feeling, which together form an emotion (Craig, 2002). Fatigue is proposed to be a regulated emotion (Noakes, 2012). The AI regulates this emotion, as there is a large increase in neural activation in the AI immediately before the cessation of exercise (Hilty et al., 2011).

The interoception pathway can be manipulated psychologically through mood regulation to appraise a stimulus differently (Rainville et al., 1997). Negative mood states significantly increased the rating of stimulus unpleasantness (Villemure et al., 2003).

Inducing a positive mood state through music, humorous movies and audiotapes, and exercise reduces the perception of pain (Good, 1996, Cogan et al., 1987, Weisenburg et al., 1998, Focht et al., 2002, Critchley et al., 2002). A positive mood state does not decrease the rating of intensity of a noxious stimulus relative to a negative mood state, however it does reduce the participant's rating of perceived unpleasantness of the stimulus (Villemure et al., 2003). Therefore, manipulating a mood state affects the affective appraisal of a stimulus.

Paulus et al. (2009) proposed a hypothesis that interventions working directly on the ACC and AI will improve performance in adverse environments because these brain structures regulate afferent feedback to maintain homeostatic balance. Elite adventure racers demonstrate better cognitive performance and lower activation of both ACC and right AI compared to untrained individuals during non-hypercapnic inspiratory breathing loads (Paulus et al., 2012). This points to both the ACC and AI activation patterns as being important paralimbic structures for optimal performance in adverse environments. This is consistent with research utilizing pharmaceutical manipulations of dopamine, which increases motivation and arousal, particularly in thermally stressful conditions (Roelands & Meeusen, 2010). Specifically, administration of dopamine reuptake inhibitors increases the time to voluntary fatigue (Bridge et al., 2003) and increases exercise performance (Roelands et al., 2008) in the heat, but not in thermoneutral environments (Meeusen et al., 1997, Watson et al., 2003).

MST may work directly on the ACC (motivational component) and the AI (through affective re-appraisal). If MST improves endurance capacity it will be because through continuous conscious re-appraisal will activate these paralimbic structures in order to delay the attainment of voluntary fatigue. Furthermore, if MST has any influence on cognitive function, it would most likely be for executive function tasks. The rationale behind this statement is that executive function occurs in the ACC, so by using MST it could potentially shift neural resources to the ACC, making more resources available for higher-order executive function tasks, as opposed to reaction time or working memory tasks that occur in different regions of the brain. If MST leads to an increase in endurance capacity, then there is potential for improvement in executive function after the TTE because of the neuronal shift to the ACC and AI through active motivation and re-appraisal strategies. Therefore, if there is an improvement in endurance capacity or executive function task, than interoception and the spino-thalamic pathway would provide the psycho-neurobiological-physiological pathway for this occurrence.

2.7 Future Directions

Future research is needed to understand how cognitive, behavioural, and subjective responses vary with severity of heat stress, not only because there is a reduction in endurance performance, but because psychological changes precede the onset of critical physiological changes (Kobrick & Johnson, 1991). There are also significant functional changes that occur in the brain with hyperthermia, which a psychological intervention may be helpful for.

There are limited studies manipulating psychological component of endurance performance in the heat (Barwood et al., 2008, Castle et al., 2012). Based on the success of the psychological skills training package used in Barwood et al. (2008), a follow up study should be conducted to see if one specific psychological skill such as MST could be strong enough to increase endurance performance in the heat, similar to the positive effect it has in thermoneutral temperatures (Blanchfield et al., 2014). Furthermore, there has yet to be a study to test if a psychological intervention can be effective when participants start the performance test in a hyperthermic state, so it is unknown if psychological skills training can improve exercise performance at a high internal temperature.

One key element of psychological skills training, including MST that needs to be addressed is its effect on cognitive performance. To date there have been no studies testing the effect of psychological interventions on cognitive function in the heat. With the neurophysiological changes (e.g. decreases in cerebral perfusion), neuropsychological changes (e.g. reduction in drive, mood), and the increased difficulty in performing cognitive tasks (e.g. limited neural resources), hyperthermia and heat may be the ideal testing environment. Qualitative evidence proposes that motivational self-talk increases performance by increasing focus, alertness, and maintaining an optimal state of arousal (Hatzigeorgiadis et al., 2004). However, this has yet to be tested in thermoneutral or hot environments.

MST could potentially influence the psychological response to exercise in the heat. These changes could manifest as changes in mood and the perception of effort. Monitoring mood may be a useful early indicator on changes in psychological function in the heat (Lane et al., 2004). MST could work to reframe the stress response to the psychophysiological demands and perceived capability to cope with these demands while exercising in the heat (Acevedo & Ekkekakis, 2001). Therefore if there is an improvement in mood or maintenance of baseline mood state, this could lead to an increase in exercise performance (Lane et al., 2004). However, research is necessary to determine this response. Therefore future research should look into whether or not intervening with MST can improve cognitive, exercise, and subjective responses in the heat (Figure 2.7.1)

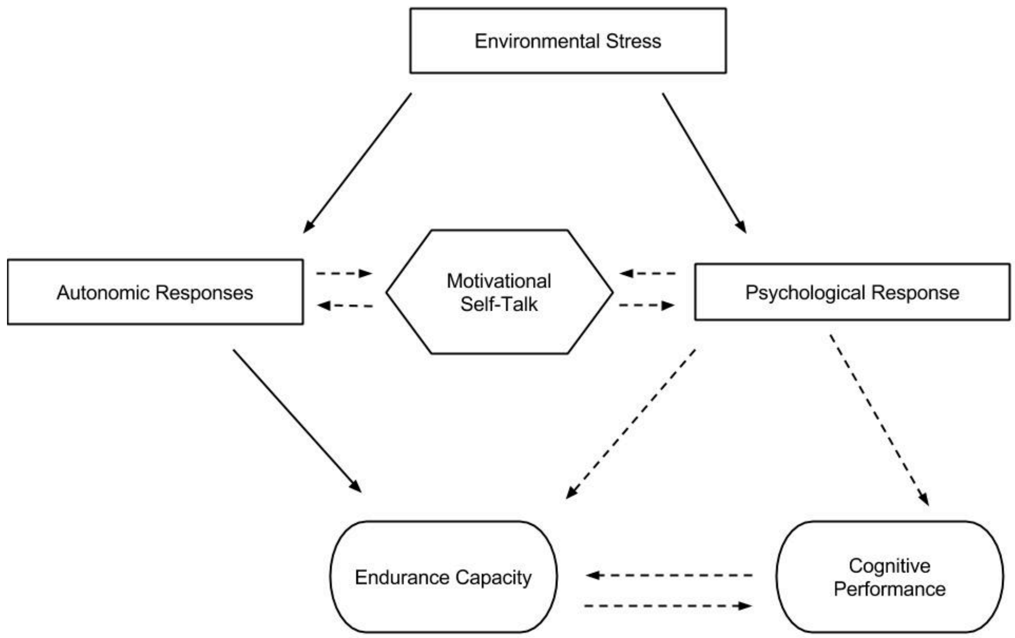

Figure 2-9 - Proposal for how motivational self-talk could affect exercise performance and cognitive performance in the heat. (--->) dictates the relationship to be assessed in this thesis, while (—>) represents factors already known to be influential in effecting performance.

3 Objective of Thesis

The main objectives of this thesis are to examine the psychophysiological response of using the psychological intervention of motivational self-talk (MST) on endurance and cognitive performance in the heat compared to no intervention (CON). The thesis is designed to test the following:

1) To examine the effect of motivational self-talk on endurance capacity during a time to exhaustion test (TTE). It is hypothesized that: there will be no differences between MST and CON on any physiological variables during the TTE, however, MST will increase TTE for Exercise 2, while there will be no improvements in the CON condition.

2) To examine the effect of motivational self-talk on cognitive function following exercise in the heat. It is hypothesized that there will be an improvement in executive function, working memory and information processing with MST during the cognitive test battery performed.

A secondary objective of this thesis is to see if a top-down cognitive strategy will influence the subjective appraisal of exercising in the heat. The following experiment is designed:

3) To examine if motivational self-talk influence the subjective responses of ratings of perceived exertion during, and mood responses following, exercise in the heat. According to the Psychobiological Model of Endurance Exercise and the Central Governor Model,

MST may have a beneficial effect on participant's perceptions and appraisal of exercise. It is hypothesized that the MST group will have lower RPE scores and maintain a positive mood state compared to the CON group.

4 Methods

4.1 Participants

The experimental protocol and procedures were approved by the Bioscience Research Ethics Board at Brock University (REB #14-162), and conformed to the latest revision of the Declaration of Helsinki. All participants were screened using a modified Physical Activity Readiness Questionnaire and a full explanation of procedures, discomforts, and risks were given prior to obtaining informed written consent.

14 male and 4 female cyclists and triathletes (aged 18-50) volunteered for this experiment, then were matched by sex and randomly selected (www.random.org) to receive either two-weeks of motivational self-talk training (MST) (n = 9) or a two-week control phase (CON) (n = 9). There were no differences ($p > 0.05$) for age, height, body mass, maximal oxygen consumption, peak power output, cognitive failure questionnaire score, and peg board score between the CON and MST groups (Table 4.1). Based on DePauw et al. (2013), participants are classified as performance level 3 (scale of 1–5). Female participants completed the experimental sessions during 7-10 days and 21-24 days of their menstrual cycle.

Variable	CON (n = 9)	MST (n =9)
Mass (kg)	175.8 ± 6.3	176.2 ± 7.5
Height (cm)	72.0 ± 10.3	75.8 ± 10.3
Age (yrs)	39.0 ± 10.1	39.0 ± 8.8
% Body Fat	14.5 ± 4.6	13.7 ± 4.2
$\dot{V}O_{2peak}$ (mL·kg·min^{-1})	61.8 ± 6.0	59.0 ± 8.4
PPO (W)	338 ± 40.2	344 ± 50.0
Cognitive Failure Score	25.4 ± 8.5	27.3 ± 5.1
Purdue Peg Board	35.0 ± 2.3	31.0 ± 1.7

Table 4-1- Participant characteristics for CON and MST groups. All data is presented as the Mean ± SD. There was no difference ($p > 0.05$) between groups on any participant characteristics.

4.2 Experiment Design

The experiment implemented a pretest-posttest design where participants visited the lab a total of 4 times (Figure 4.1). The first session consisted of collecting anthropometric data, completing baseline cognitive testing, and a peak oxygen consumption ($\dot{V}O_{2peak}$) test on a cycle ergometer. The second session was a familiarization trial (Figure 4.2). The third (PRE) and fourth (POST) sessions were the experimental sessions, which follow the same testing protocols as the familiarization trial (Figure 4.2). Sessions 1-3 were separated by a minimum of 1 week to ensure proper recovery time and reduce the potential effects of heat acclimation. Sessions 3-4 were separated by 14 days, during which a psychological intervention consisting of MST or no intervention (CON) was given. The protocol is explained in more detail below:

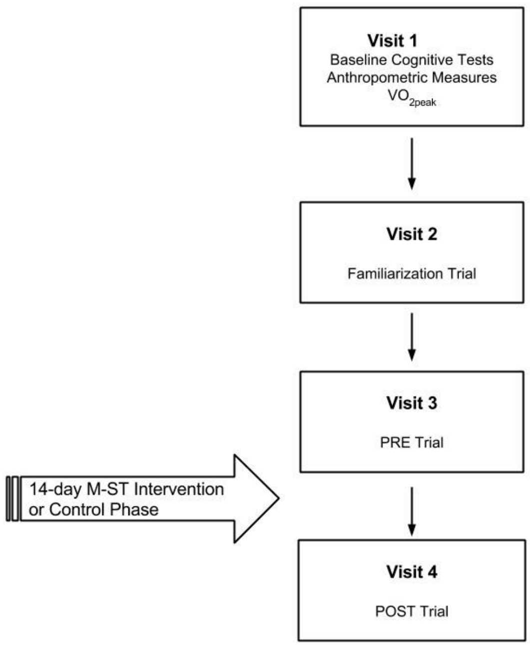

Figure 4-1 Experimental Protocol.

4.3 Session 1- Baseline Cognitive Performance, Anthropometric Data and Peak Maximal Oxygen Consumption Test

Participants provided their age (years) as well as had their height (cm) and mass (kg) measured upon arrival. To determine body density, skin fold thickness was measured at seven sites (triceps, sub-scapula, abdomen, supra-iliac crest, mid-axilla, thigh, and pectoralis major) (Jackson & Pollack, 1978). Percent body fat was calculated using the Siri (1961) equation.

As a baseline measure of general fluid intelligence, participants were asked to complete the Cognitive Failure Questionnaire (CFQ) (Broadbent et al., 1982). The CFQ is a 25-item questionnaire that is a self-evaluative measure of cognitive performance. The CFQ items test for spatial orientation failures, memory lapses, motor functioning, and is related to four factors of absentmindedness (memory, distractibility, blunders, and names). Items were scored on a 5-point Likert scale where 0 equals "never" and 4 equals "very often". CFQ scores can range from 0 to 100, where average CFQ scores are between 19 and 45 (Wallace, Kass & Stanny, 2002). Participants were excluded from the study if CFQ score is > 45, as this score indicates considerable difficulties in completing tasks that require vigilance. As a baseline measure of manual dexterity, participants performed the standardized 60 s Purdue Pegboard Assembly test (Lafayette Instrument, Lafayette, IN). Participants practiced the test until scores reached asymptotic levels in order to reduce the learning effect, then performed the test a total of 5 times, with the highest score used as peg board score.

Peak oxygen consumption ($\dot{V}O_{2peak}$) was determined in a thermoneutral environment (~22°C, 30% relative humidity (RH)) on a cycle ergometer (Velotron, RacerMate Inc, Seattle, WA). Male participants begun the test by completing a 5-minute warm-up at 100 Watts (W), followed by an incremental increase in workload of 25 W every minute until exhaustion; females began at 100 W and increase workload by 20 W each minute. A soft silicone facemask connected to an online gas collection system was worn throughout the test to collect expired gases and determine $\dot{V}O_{2peak}$, defined as the highest 30 s value. The highest power output achieved during the last full 1-minute stage was used to determine Peak Power Output (PPO) (Blanchfield et al., 2014).

4.4 Session 2- Familiarization and Practice

A familiarization trial (FAM) was scheduled prior to the commencement of the two experimental sessions to ensure that the participants were able to fulfill the requirements of the exercise protocol. The familiarization trial was identical to the experimental trials (Figure 4.2), which are explained in greater detail below.

4.5 Sessions 3 & 4- Experimental Trials

Upon arrival, participants voided their bladder and nude body mass was determined. Urine specific gravity (USG) was measured with a refractometer (PAL-10S, Atago, Tokyo, Japan). Participants were considered euhydrated if USG is ≤1.020, or else the test was rescheduled. Participants were instrumented, then seated in a chair and completed a baseline measure of mood and a cognitive test battery (CTB, see below for details) in a thermoneutral (22°C, 30% RH) environment. Participants then entered an environmental chamber (Can-Trol Environmental Systems, Markham, ON) set at 35.0°C, ~50% RH, 3.0 $m \cdot s^{-1}$ airflow, and were fitted with a soft silicone mask in order to collect expired gases. Participants were dressed in an ensemble consisting of cycling bib shorts and cycling shoes, which participants provided for each session.

The first exercise period (EX1) consisted of constant load cycling with a 5 minute cycling warm up at 100 W followed by 25 minutes of cycling at 60% of PPO. Participants were allowed to freely choose their cadence between 60-120 rpm. The only time feedback participants received were when perceptual scales (explained in more detail below) were asked.

Upon completion of EX1, participants dismounted the cycle ergometer, body mass was measured, and then sat in a chair inside the environmental chamber with air flow stopped for the first 30 minute rest period (R1). Participants wore a 100% Vinyl poncho in order to stabilize thermal load during the rest period. 250 mL of water were provided *ad libitum* to reduce the physical and perceptual strain of thirst and was only provided during rest periods. Participants completed an assessment of mood and the CTB which were completed at ~20 minute mark. A set time period was chosen for the rest periods in order to prevent participants from rushing through the CTB to finish the period sooner.

Upon completion of R1, participants performed the sond exercise bout to determine endurance capacity. The sond exercise bout consisted of a 5 minute warm-up at 125 W followed by a Time To Exhaustion (TTE) test performed at 80% PPO (Blanchfield et al., 2014). Participants were allowed to freely choose their cadence between 60-120 rpm. The TTE was terminated due to 1) volitional fatigue, 2) cadence dropped below 60 rpm for 5 consecutive seconds, or 3) a T_{re} of 40.0°C for 1 min. No verbal encouragement was given during the TTE to eliminate the superimposition of any extraneous verbal statements (Blanchfield et al., 2014). Participants were not told of the duration of their TTE to minimize goal-setting in future tests. Upon completion of the TTE, participants completed a second rest period (R2), which was identical to R1.

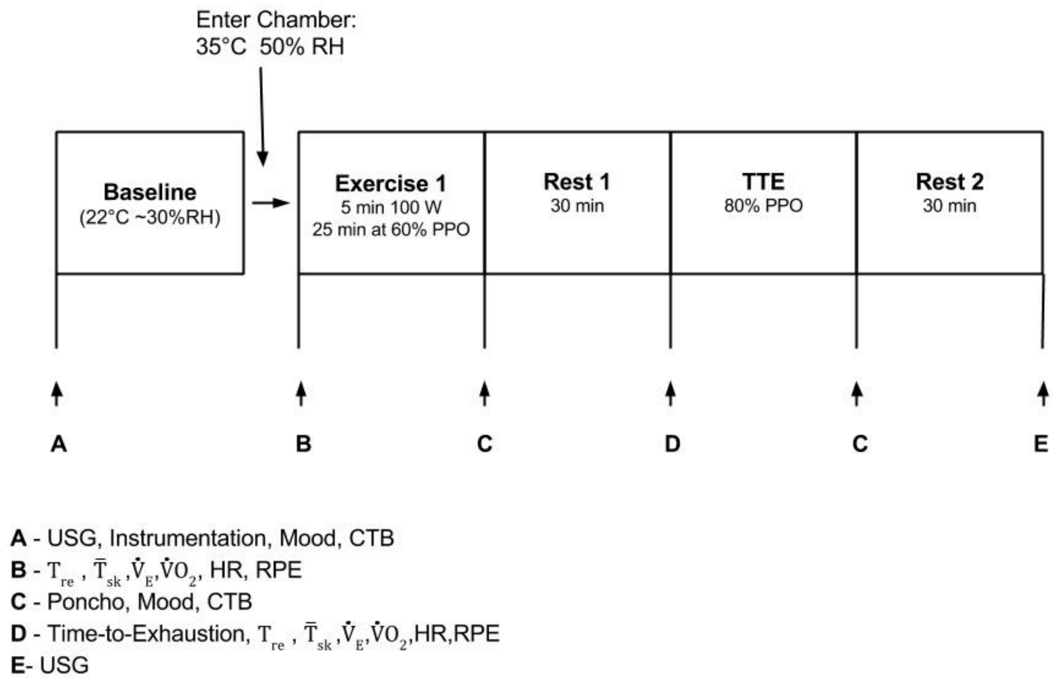

Figure 4.2- Experimental Protocol for FAM, PRE, & POST.

4.6 Motivational Self-Talk Intervention

Participants were randomly selected to receive a two-week MST intervention or a two-week control phase (CON) between the PRE and POST sessions. The MST intervention was given in two stages through the use of a skills training workbook (Thelwell & Greenless, 2003, Blanchfield et al., 2014, Barwood et al., 2015). The workbook was designed to contextualize self-talk cues to the demands of the exercise (Landin, 1994).

The first stage consisted of two self-talk exercises, one that focused on exercise performance and the second that focused on cognitive performance. Participant's first determined a list of negative statements that occurred during the EX1 and TTE periods in the PRE trial. Participants then compared their list of negative statements to a list of 12 motivational statements ('Keep Pushing, You're Doing Well') used in previous self-talk literature (Barwood et al., 2015, Blanchfield et al., 2014). Participants then determined their own list of 5 motivational self-talk statements. From the two lists (totaling 17 statements), participants then chose two statements that they deemed will be helpful for EX1 and two statements for TTE. The 2nd exercise of the first stage focused on developing one motivational self-talk statement to help optimize cognitive performance. Participants generated a list of negative statements and compared them to a list of 5 positive/ motivational self-talk statements (e.g. "I am focused"). Participants then generated one statement that they deemed will be the most beneficial to use before and during each cognitive test in the POST trial.

The second stage of the workbook was a two-week practice phase in order to adapt and self-contextualize the use of statements to optimize performance. Participants were required to perform a minimum of 3 aerobic sessions in order to practice their MST statements. After each exercise session, participants completed a workbook protocol assessing the efficacy, frequency, and their comfort with the 4 chosen exercise self-talk statements. Effective statements were recorded and participants continued to use them in future exercise sessions. Ineffective statements were rephrased or replaced with a more suitable statement chosen by the participant. Participants were told to perform their normal training regimen, however due to the personalized nature of practice, participants were in control of their workouts and freely chose the duration and exercise intensity of their workout sessions. An experimenter was available throughout the practice period if the participant needed any assistance with their workbook. Self-talk usage during practice periods was assessed using an 11-point (0= not at all, 10= greatly) Likert type scale asking participants to what extent did they use self-talk during the session.

The CON group performed a two-week control phase where they resumed their normal training regimen. The experimenter verbally asked participants if they had any changes in their exercise regimen between the PRE and POST trials.

4.7 Cognitive Test Battery

To measure progressive cognitive changes throughout the experiment the CTB consisted of a Groton Maze Learning Task, Detection Task, Two-Back Task, and a Set-Shifting Task, which took approximately 15 minutes to complete. Baseline cognitive measures were taken before entering the environmental chamber in a thermoneutral environment. The CTB was taken again during R1 and R2 inside the environmental chamber.

4.7.1 Groton Maze Learning Task

The Groton Maze Learning Task (GMLT) (CogState, New Haven, CT) is a touch screen based cognitive task of working memory function and information processing ability (Pietrzak et al. 2008). The test specifically measures executive function through error detection and spatial memory. The test consists of a 10 x 10 grid of square trials that cover a hidden 28-step pathway that includes 11 turns. A blue tile on the top left corner of the screen indicates the starting position and a red circle on the bottom right corner indicates the finish location. The GMLT is performed seven times (initial test sequence, five block trials and one delayed recall trial). The GMLT test sequence required approximately 5 to 10 minutes to complete. The delayed recall test was performed at the end of the CTB to test spatial working memory. Each maze is randomly selected from a bank of 20 versions of the task, each with the same level of difficulty, in order to eliminate a learning effect upon repeated exposure. Therefore, completing one maze does not prepare the participants for different version of the maze. Performance is measured for speed (ms) and for total errors made, where a lower score indicates a better performance. The total duration (s) and total # of errors with be measured during the five-block period to determine learning. The final maze in the five blocks (GMLT-5) total errors and speed were compared with the delayed recall trial (GMLT-Recall) to determine spatial working memory.

4.7.2 Two-Back Test

The Two-Back Test is a measure of attention and visual working memory (CogState, New Haven, CT). The test starts with pre-task instructions asking if the card presented is identical to the card presented two cards ago. At the start of the task a card will be presented face up on the center of the screen, and the participant can either answer 'Yes' or 'No' on whether or not the card presented as the same as two cards ago. The first two answers will always be No, and then the test will begin. There are a total of 48 cards presented. The participant was encouraged to work as quickly and as accurately as possible and not to answer before a card is shown. Performance was measured in the arcsine proportion of correct answers and accuracy of performance. For this task, a higher score indicates a better performance. Total duration to the complete the two-back test was approximately 2 minutes.

4.7.3 Detection Task

A Detection Task was used to test the psychomotor function and reaction time. The participant was asked if the card shown is turned over. A playing card will be presented in the center of the screen. Once the card flips over the participant must select 'Yes'. This process continues until the task is completed. There is an interstimulus interval of 2 seconds between each presentation of 35 cards. Performance was measured for speed (mean of the log10 transformed reaction times for correct responses) where a lower score represents a better performance. The task takes approximately 2 minutes to complete.

4.7.4 Set-Shifting Task

The Set-Shifting Task was used to test executive function and decision-making. The participant is presented with a playing card is presented at the center of the screen and needs to determine if the card presented contain a target stimulus dimension (either number or colour). The participant must learn the correct target card by answering "Yes" or "No". The participant is taught the specific dimension of the card is correct by receiving feedback from the program, as the next card will not be displayed until the correct response has been made. As the task continues, the target or correct stimulus dimension changes through intra-dimensional shifts (e.g. from red to black), extra-dimensional shifts (e.g. from number to colour), or the correct card stimulus shifts. Participants are not told when these shifts occur and must re-learn the new target rule to proceed through the task. Performance was measured base on the total # of errors where a lower score indicates a better performance.

4.8 Signal Processing

All physiological variables were analyzed using 1-minute averages at every 5 min time-point in EX1, R1, and R2. Due to the individual variation of TTE times, data (T_{re}, $\overline{T}_{sk}$, HR, $\dot{V}_E$, $\dot{V}O_2$, Cadence, RPE) was converted into relative isolated time points for the TTE test. The TTE time points used were $t = 0$, iso-50%, iso-75%, and iso-100%.

4.8.1 Temperature

Rectal temperature was measured with a flexible thermistor (Mon-A-Therm Core, Mallinkrodt Medical, St Louis, MO) inserted 15 cm beyond the anal sphincter, collected through a partitional calorimetry unit (PCU). Data was displayed and saved on a custom user interface developed in LabView. Rectal temperature data was exported and reduced in Matlab to analyze the change over the course of the experiment.

Heat flux sensors were used to measure mean skin temperature ($\overline{T}_{sk}$) collected through the PCU through four sites: chest, arm, thigh, and leg and was determined using the Ramanathan (1964) equation:

$$\overline{T}_{sk} = 0.3T_{chest} + 0.3T_{arm} + 0.2T_{thigh} + 0.2T_{leg}$$

All temperature data was continuously sampled at 1 hertz.

4.8.2 Metabolic Data

Expired gases were collected through a soft silicone facemask with the exhalation port connect to a metabolic cart ((ML206 Gas Analyzer, ADInstruments Inc. Colorado Springs CO). Expired gas from the breathing apparatus was continuously sampled during

EX1 and TTE to determine minute Ventilation ($\dot{V}_E$) (L/min), and Volume of Oxygen ($\dot{V}O_2$) (L/min).

4.8.3 Heart Rate

Heart Rate and R –R intervals was sampled continuously using a telemetric heart rate monitor (RS800CX, Polar Electro Oy, Finland). Data is sampled at 10 hertz and will be reduced in MatLab to determine beats per minute.

4.9 Perceptual Scales

Perceptual measures of exercise, thermal comfort and sensation were recorded at t = 0, 5, 10, 20, and 30-min during EX1 and only RPE was taken a t= 0 and every 2 minutes during the TTE. Participants were not deceived for the measure and were aware that RPE was taken at every 2 min mark. Thermal comfort and sensation were sampled during R1 and R2, pre-mood scale, pre-CTB, and post CTB measurements. RPE was assessed using a 6-20 scale (Borg, 1982). TC was assessed on a 1-4 scale, while TS was reported on a 1-7 scale (Gagge et al., 1967).

The Brunel Mood Scale (BRUMS) was used to assess mood before the CTB during baseline, R1, and R2. BRUMS is a validated 24-item profile of mood states questionnaire (Terry et al., 1999, Terry, Lane, & Fogarity, 2003), and includes six subscales (anger, confusion, depression, fatigue, tension, and vigour) with a subscale consisting of four items. Items are answered on a 5-point Likert scale (0= not at all, 1 = a little, 2 = moderately, 3= quite a bit, 4 = extremely). The raw scores was used to determine mood state.

4.10 Statistical Analysis

Data are presented as the mean ± SEM. Normal distribution was assessed, and if the assumption of sphericity could not be met, the Greenhouse–Geisser correction was used. All continuous variables were analyzed using separate Group (MST vs. CON) x Trial (PRE vs. POST) x Time mixed-model Repeated Measures ANOVA. All cognitive data was analyzed using separate Group (MST vs. CON) x Trial (PRE vs. POST) x Time (Baseline vs. R1 vs. R2) mixed-model Repeated Measures ANOVA. Spatial memory recall for the GMLT was compared using a Group (MST vs. CON) x Variable (Trial 5 vs. Recall) x Trial (PRE vs. POST) x Time (Baseline vs. R1 vs. R2) mixed-model Repeated Measures ANOVA. A Bonferroni post hoc analysis was use to test significant main effects. Paired sample *t* tests were performed to test significant main effects at specific time points within-group effects. All ordinal data (RPE, TS, TC) was analyzed using separate Group (MST vs. CON) x Trial (PRE vs. POST) x Time mixed-model Repeated Measures ANOVA, with a Wilcoxon signed-rank test used to compare within-group effects at specific time points. Ordinal data are presented as the median (quartiles 1 and 3). Statistical significance was set at $p < 0.05$. All analyses were performed using IBM SPSS Statistics for Windows (version 22.0; IBM Corp., Armonk, N.Y., USA).

5 Results

Post-experiment questionnaires revealed that the MST-Intervention created two distinct conditions in the POST trial. The MST group used 2 motivational self-talk statements in EX1, 2 statements in TTE, and 1 statement during the CTB. Participants in the CON group reported using some forms of self-talk, arousal regulation strategies (e.g. focus on breathing), disassociation, and goal-setting, however, these strategies were unstructured and unplanned.

5.1 Exercise 1

There was no group x trial x time interaction ($p = 0.337$) in baseline urine specific gravity in both MST (Pre: 1.012 ± 0.001, Post: 1.009 ± 0.004), and CON (Pre: 1.009 ± 0.003, Post: 1.009 ± 0.005), with no group x trial x time interaction ($p = 0.337$). There was a significant increase (all $p < 0.05$) in T_{re} (Figure 5.1), $\overline{T}_{sk}$ (Figure 5.3), HR (Figure 5.4), $\dot{V}_E$ (Figure 5.5), $\dot{V}O_2$ (Figure 5.6), RPM (Figure 5.7), RPE (Figure 5.8), TC (Figure 5.9), and TS (Figure 5.10) over the course of EX1, with no trial x time x group (all $p >$ 0.05) interaction for any physiological variables between the CON and MST groups. Due to slippage of the rectal thermistor, T_{re} was analyzed with $n = 15$ for the MST ($n = 8$) and CON ($n = 7$) groups. The exercise bout was successful in raising $T_{re} > 1.0$°C as core temperature significantly (both $p < 0.05$) increased in both MST and CON conditions, with no trial x time x group interaction ($p = 0.115$). Rectal temperature significantly increased in MST in both PRE (Start: 37.5 ± 0.22°C End: 38.6 ± 0.24°C, Δ +1.1°C) and POST (Start: 37.5 ± 0.27°C End: 38.5 ± 0.31°C, Δ +1.0°C) with no differences at any time point. Rectal temperature significantly increased in CON in both PRE (Start: 37.2 ±

0.2°C End: 38.3 ± 0.12°C, Δ +1.1°C) and POST (Start: 37.2 ± 0.16°C, End: 38.4 ± 0.25°C, Δ +1.2°C).

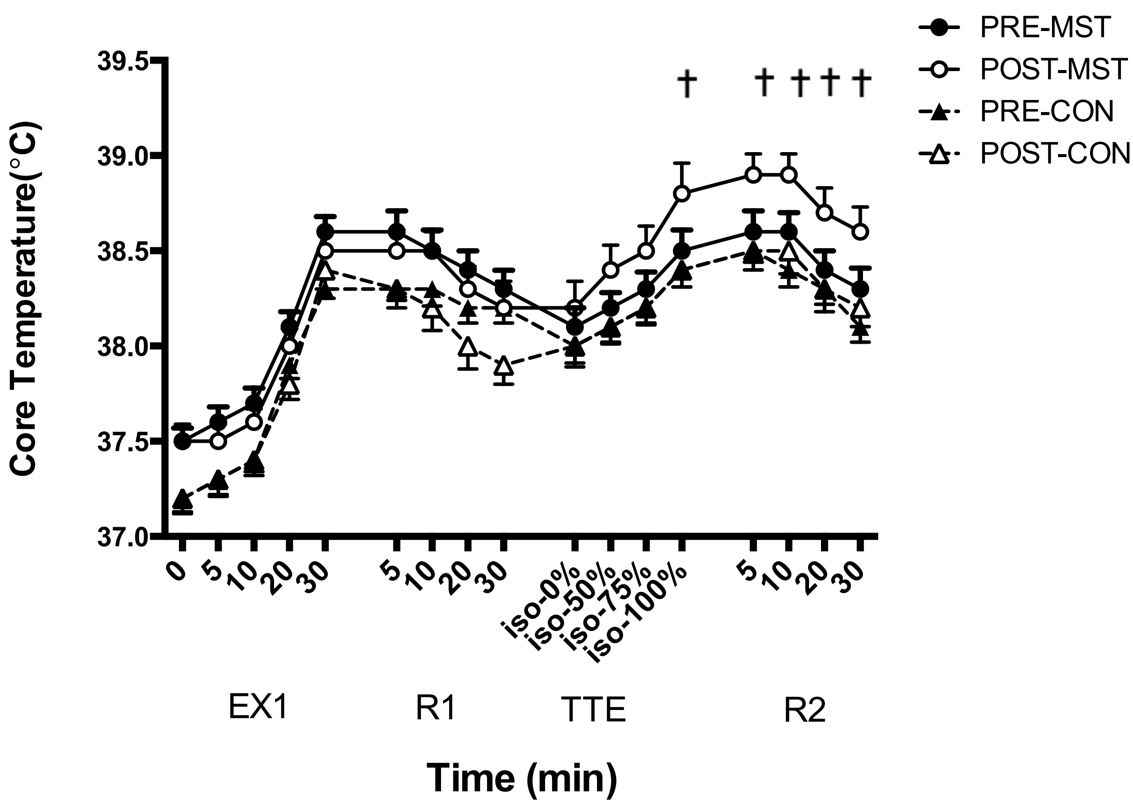

Figure 5-1- Rectal temperature response over the course of the trial. † indicates significant difference from PRE to POST trials in the MST group.

5.2 Time To Exhaustion

There was a significant group x trial interaction ($F_{(1,16)}$= 14.460, p = 0.002) (Figure 5.2) in endurance capacity. In the CON group, there was a non-significant (p = 0.280) -4% change in TTE from PRE (531.0 ± 178.2 s) to POST (509.8 ± 216.1 s). The MST group had a significant (p = 0.021) increase in TTE by 30% from PRE (486.6 ± 172.9 s) to POST (679.0 ± 250.8 s), with all but 1 participant improving their TTE.

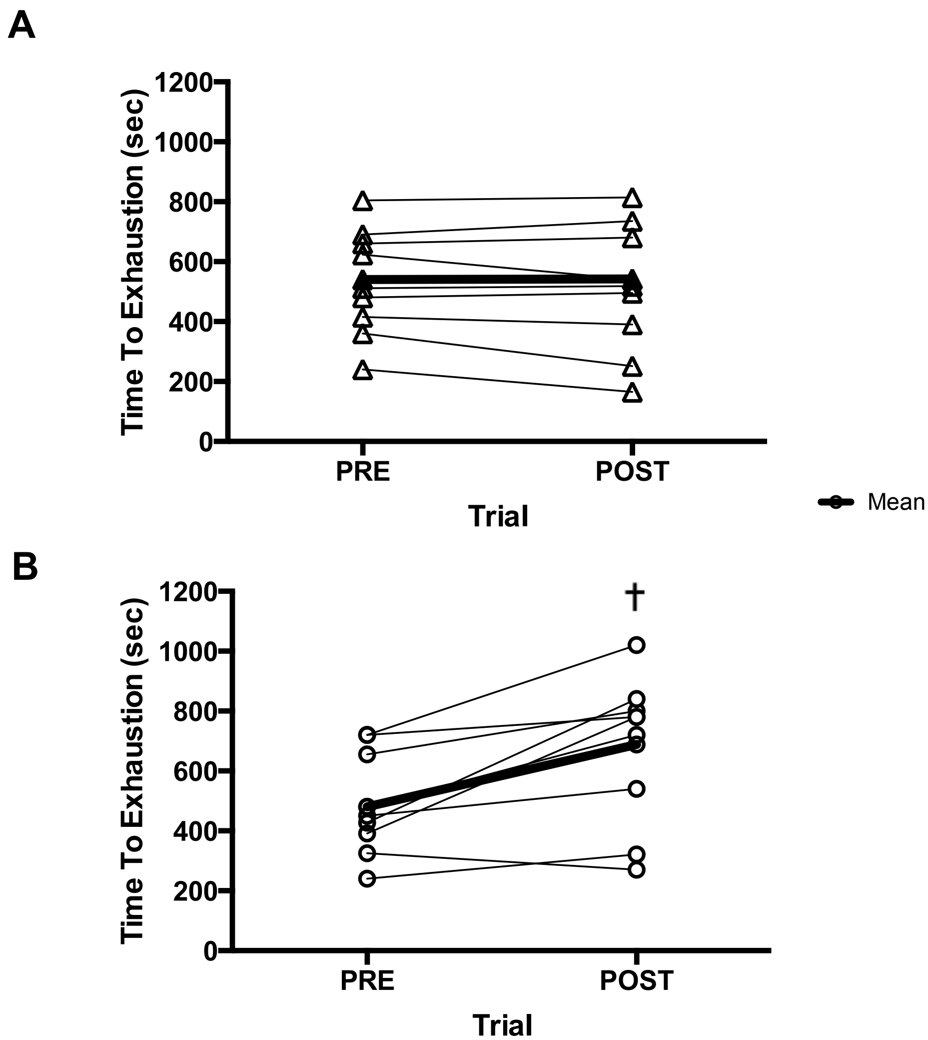

Figure 5-2- Time to Exhaustion times for CON (A) and MST (B) groups. † indicates significant difference from PRE to POST in the MST group.

Rectal temperature significantly increased over the TTE in both groups, with a significant trial x time interaction ($F_{(3,30)} = 3.766$, $p = 0.021$). Follow up tests revealed that there were no differences (all $p > 0.05$) at any time-point in T_{re} for the CON group. The MST group finished with a significantly higher T_{re} by 0.3°C at iso-100% of the TTE in POST (38.8 ± 0.42°C) compared to the PRE trial (38.5 ± 0.26°C, $p = 0.023$), with no differences at iso-0% of the TTE (PRE: 38.1 ± 0.25°C, POST: 38.2 ± 0.36°C) or at iso-

50% and iso-75%. Mean Skin Temperature, $\dot{V}_E$, $\dot{V}O_2$, and HR significantly increased (all $p < 0.05$) over the TTE with no group x time x trial interaction (all $p > 0.05$) between CON and MST conditions.

Perception of effort increased ($p > 0.05$) over the course of the TTE with no group x trial x time interactions ($F_{(3, 39)}$ 1.196, $p = 0.324$) or differences at any time-point. The MST group rated the overall extent of usage of self-talk statements significantly ($p = 0.046$) higher in the TTE (9 (8.5-10)) compared to EX1 (8 (6.25-9.75). Participants also rated the overall effectiveness of self-talk statements significantly ($p = 0.026$) higher in TTE (10 (9-10)) than in EX1 (8 (6-9.5)).

5.3 Cognitive Test Battery

Post experiment questionnaires revealed that the MST group used 1 motivational self-talk statement during the CTB in the POST trial, with the overall extent of usage was 8 (3-10) and the perceived overall effectiveness of the statement used 7 (5.5-10). Qualitative questionnaires revealed participants used MST to increase ‘focus’ and ‘concentration’ on the tasks. The CON group did not report any self-talk or psychological strategy usage during any portion of the CTB.

5.3.1 GMLT

There were no significant group x time x trial interactions for both learning duration ($F_{(2,30)} = 0.295$, $p = 0.747$) (Figure 5.11) and the # of errors made ($F_{(2,30)} = 0.765$, $p = 0.474$) (Figure 5.12) on the 5 block GMLT. However, there was a significant trial interaction for both learning duration ($F_{(1,16)} = 11.798$, $p = 0.005$) and the # of errors made ($F_{(1,16)} = 5.972$, $p = 0.027$) on the 5 block GMLT. MST led to a significantly faster completion in the POST trial at baseline (PRE: 164.5 ± 9.8 s, POST: 152.7 ± 9.0 s, p = 0.009) and in R2 (PRE: 155.2 ± 5.5 s, POST: 118.4 ± 18.3 s, p = 0.039), but not during R1 (PRE: 158.4 ± 12.7 s, POST: 144.8 ± 7.5 s, p = 0.164), as well as fewer errors made at baseline (PRE: 46.0 ± 6.0 errors, POST: 36.5 ± 4.1 errors) and R2 (PRE: 48.0 ± 12.0 errors, POST: 40.0 ± 4.1 errors), but not during R1 (PRE: 47.0 ± 7.5 errors, POST: 45.0 ± 7.8 errors), during the learning portion of the 5 block GMLT. There were no differences in learning duration or # of errors made at anytime point in the CON group on the 5 block GMLT.

There was no trial x test x time x group interaction ($F_{(2,30)} = 0.672$, $p = 0.518$) for speed on the GMLT-Recall (Table 5.1). However, there was a trial interaction ($F_{(1,16)} = 8.232$, $p = 0.012$) for speed. Follow-up analysis revealed, the MST group approached significantly faster completion time for trial 5 at baseline (p = 0.058) and R2 (p = 0.052), with no differences at in the CON group from PRE to POST. The MST group was significantly (p = 0.038) faster at GMLT-Recall only at baseline, with no difference in CON at any time point from PRE to POST. There was no trial x test x time x group interaction ($F_{(2,30)} = 0.154$, $p = 0.858$) for # of errors made on the GMLT-Recall and no trial differences PRE-POST.

5.3.2 Set Shifting Task

There was no group x time x trial interaction ($F_{(2,32)} = 0.347$, $p = 0.710$) for # of errors made on the set-shifting task (Figure 5.13). However, there was a significant trial interaction ($F_{(1,16)} = 3.417$, $p = 0.044$) for executive function on the # of errors made on the set-shifting task. Follow up test revealed the MST group made significantly (p = 0.04) fewer errors at baseline in the POST (14.7 ± 5.2 errors) compared to PRE (19.1 ±

9.5 errors), with no differences in R1 or R2, while there were no significant changes at any time point for the CON group.

5.3.3 Detection Task

There was a significant trial x time x group interaction ($F_{(1,30)} = 4.183$, $p = 0.025$) for reaction time on the detection task (Figure 5.14). Follow up tests revealed the MST group was significantly faster ($p = 0.045$) during R2 in POST (2.493 ± 0.025 ms) compared to PRE (2.522 ± 0.026) with no statistical differences at baseline or R1. There were no statistical differences (all $p > 0.05$) in the CON group for reaction time at any time point in the CTB.

5.3.4 Two-Back Test

There were no group x trial x time interactions for both speed of processing ($F_{(2,32)} = 0.748$, $p = 0.481$) and # of errors made ($F_{(2,32)} = 0.686$, $p = 0.511$) for working memory on the two-back test (Figure 5.15). MST did not lead to any performance improvements from PRE-POST on the two-back test and there were no trial interactions (both $p > 0.05$).

5.4 Rest 1

Rectal temperature, $\overline{T}_{sk}$, HR, TC, and TS significantly (all $p < 0.05$) decreased from the start to the end of R1, with no group x trial x time interaction (all $p > 0.05$) between CON and MST. Rectal temperature decreased from the start in MST (PRE: 38.5 ± 0.29°C, POST: 38.5 ± 0.33°C), to the end of the CTB at the 20 min mark (PRE: 38.4 ± 0.29°C, POST: 38.3 ± 0.33°C), the end of R1 (PRE: 38.2 ± 0.27°C, POST: 38.2 ± 0.39°C), with a similar response in the CON condition from the start (PRE: 38.3 ± 0.1°C, POST: 38.3 ± 0.22°C), to the end of the CTB (PRE: 38.2 ± 0.26°C, POST: 38.0 ± 0.25°C), and at the end of R1 (PRE: 38.1 ± 0.21°C, POST: 38.0 ± 0.26°C).

5.5 Rest 2

Rectal temperature, $\overline{T}_{sk}$, HR, TC, and TS significantly (all $p < 0.05$) decreased from the start to the end of R2. There was a significant trial ($p = 0.002$) and group x trial ($p = 0.013$) for rectal temperature in R2. MST had a significantly ($p = 0.023$) higher T_{re} at the start of POST (38.8 ± 0.42°C) compared to the PRE (38.5 ± 0.26°C) trial, which continued throughout R2. There were no differences ($p = 0.663$) in starting T_{re} in the CON condition PRE (38.4 ± 0.21°C) or POST (38.4 ± 0.29°C), and no differences at any time point in R2. Urine specific gravity significantly decreased (both $p < 0.05$) in both MST (Pre: 1.016 ± 0.004, Post: 1.016 ± 0.004), and CON (Pre: 1.012 ± 0.005, Post: 1.013 ± 0.006), with no group x trial x time interaction ($p = 0.337$).

5.6 Mood Responses

There were no significant group x time x trial interaction (all $p > 0.05$) in mood responses between the CON and MST groups. See Table 5.2 for a detailed mood response at measurement periods from the PRE and POST trials. There was a significant time effect for both fatigue and vigour (both $p < 0.001$). Specifically, perceived fatigue significantly (all $p < 0.05$) increased over the course of the trial, while vigour significantly (all $p < 0.05$) decreased over the course of the trial. There was a time x group interaction ($F_{(2,32)} = 3.579$, $p = 0.041$) where the MST group had a significantly higher vigour at baseline compared to the CON only in the POST trial. There were no significant changes in tension, anger, confusion, or depression. Mood changes were similar between groups, and MST did not lead to any significant changes in mood state for PRE to POST.

5.7 Motivational Practice Period

Using a Friedman's ANOVA to assess participants' MST-workbook revealed that participants used significantly ($p = 0.003$) more self-talk in the 3rd practice session (9.5 (9-10)) compared to the 1st practice session (8 (5.25-8)), with no differences ($p = 0.137$) between the 2nd practice session (8 (7.25-8.75).

5.8 Manipulation Checks

5.8.1 Learning Effect of CTB

Performance on the CTB was analyzed using all participants (n =18) from the familiarization (FAM) trial compared the PRE trial to test for any potential learning effect changes due to multiple exposures to the CTB.

5.8.2 GMLT

There was a significant trial x time interaction for # of errors made ($F_{(2,34)} = 6.259$, $p = 0.028$) and speed ($F_{(2,34)} = 10.748$, $p < 0.001$) on the 5 Block-GMLT from FAM to POST (Figure 5.16). The learning effect was reduced after the third exposure of the 5 block-GMLT as there were no differences in speed at FAM-R2 (162.7 ± 11.3 s) compared to PRE-baseline (172.3 ± 10.5 s, $p = 0.242$), or number of errors in FAM-R2 (43.0 ± 3.2 errors) compared to PRE-baseline (41.0 ± 3.9 errors, $p = 0.243$).

5.8.3 Set-Shifting Task

There was no trial x time interaction ($F_{(2,34)} = 0.484$, $p = 0.621$) for # of errors made on the set-shifting task from FAM to POST (Figure 5.17).

5.8.4 Detection Task

There was a significant group x trial interaction ($F_{(2,34)} = 7.990$, $p = 0.002$) for reaction time on the detection task (Figure 5.18). Reaction time significantly improved over the course of the FAM, however there were no differences ($p = 0.503$) between FAM-R2 (2.505 ± 0.014 ms) and PRE-Baseline (2.497 ± 0.016 ms).

5.8.5 Two Back Test

There was no trial x time interaction ($F_{(2,34)} = 0.198$, $p = 0.821$) on # of errors made on the two-back test from FAM to PRE trial (Figure 5.19). There was a significant trial x time interaction ($F_{(2,34)} = 5.252$, $p = 0.010$) for speed of processing on the two-back test. Speed of processing significantly improved over the course of the FAM, however there was no differences ($p = 0.477$) between FAM-R2 (2.880 ± 0.022 ms) and PRE-Baseline (2.900 ± 0.035 ms).

5.8.6 Learning Effect of TTE

Performance on the TTE was analyzed using all participants (n =18) from the familiarization (FAM) trial compared the PRE trial to test for any potential learning effect of performing the TTE (Figure 5.20). There was a significant ($p = 0.018$) improvement in TTE time from FAM (451 ± 35.0 s) to PRE (510 ± 40.0 s) trial.

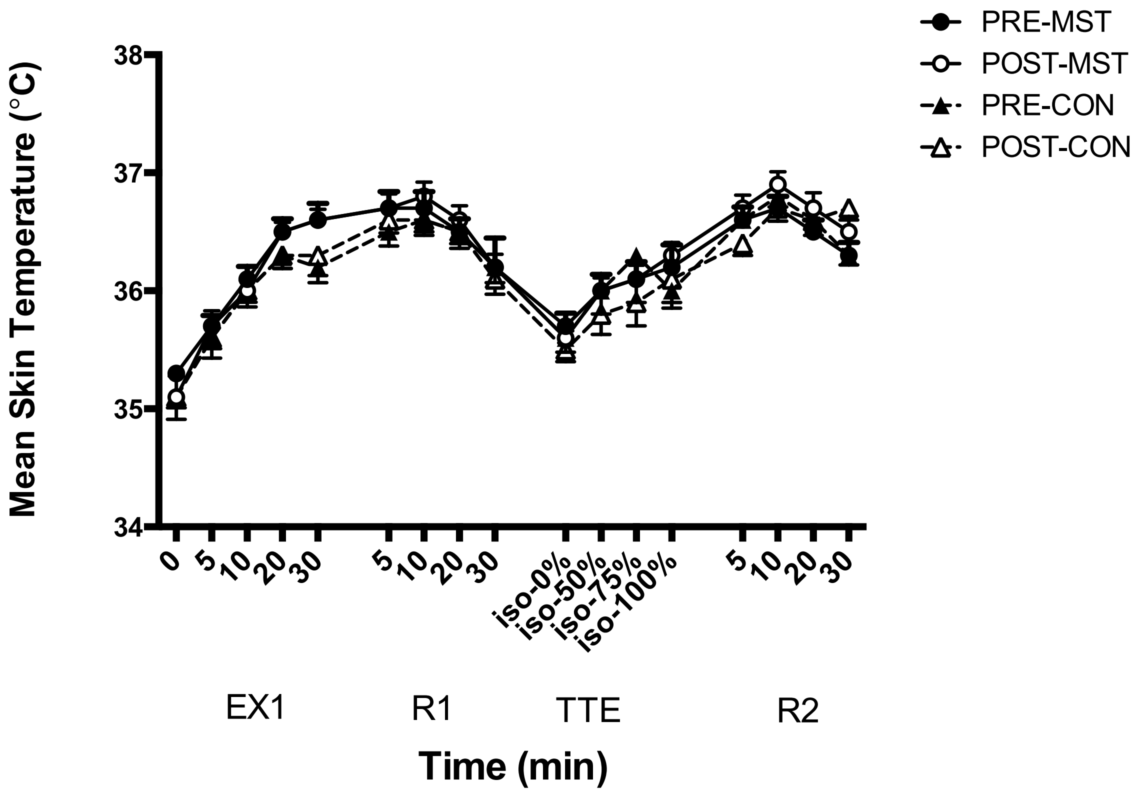

Figure 5-3- Mean skin temperature response during PRE and POST trials. All data presented is mean (± SEM).

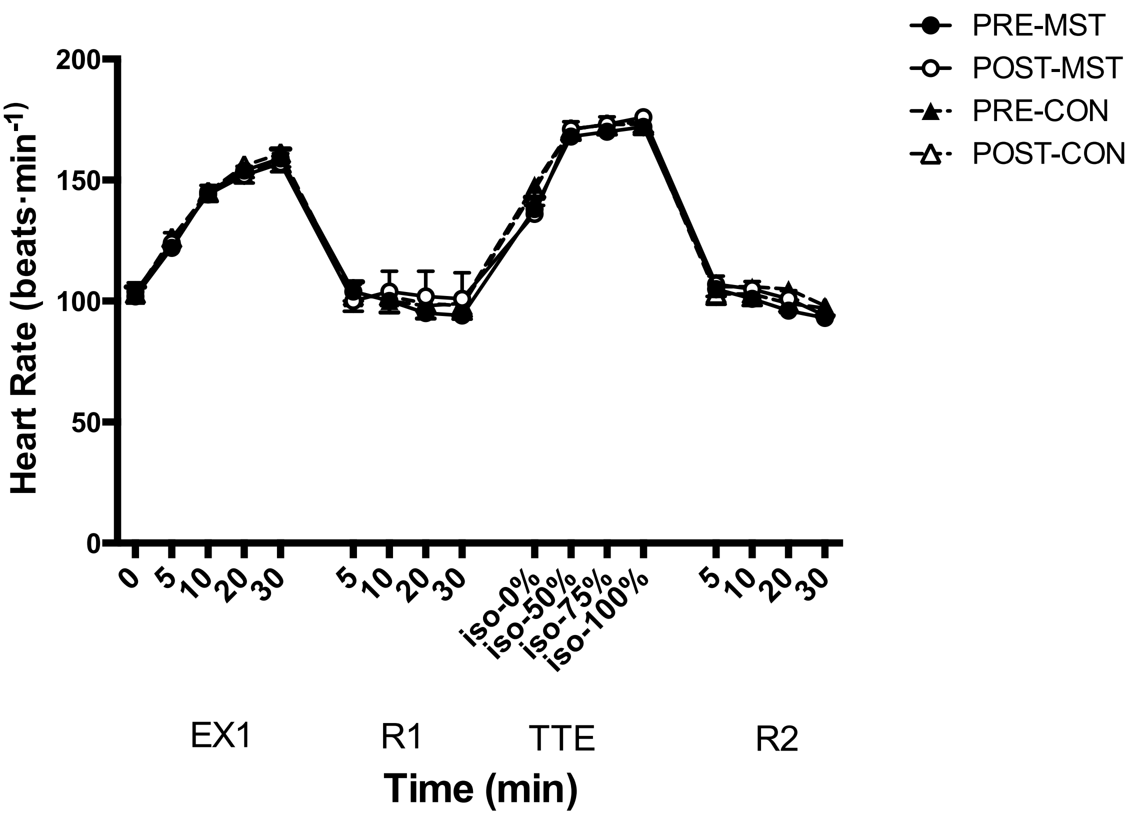

Figure 5-4- Heart Rate response during PRE and POST trials. All data presented is mean (± SEM).

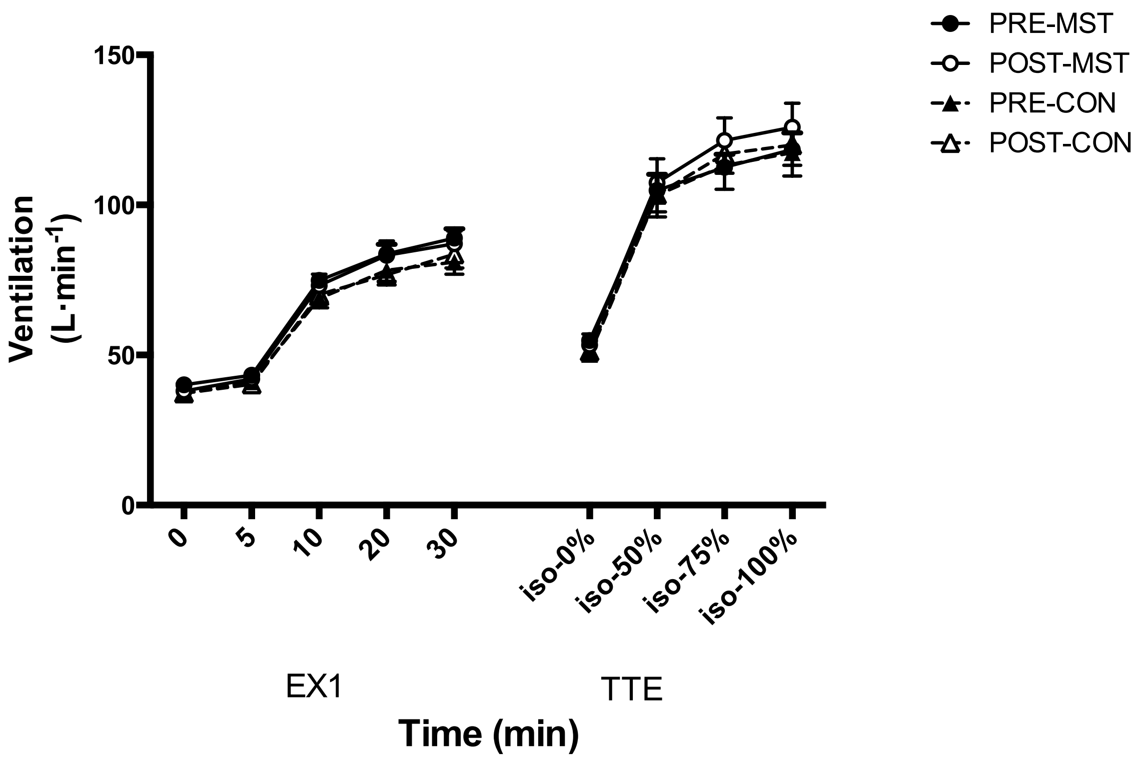

Figure 5-5- Minute Ventilation response during PRE and POST trials. All data presented is mean (± SEM).

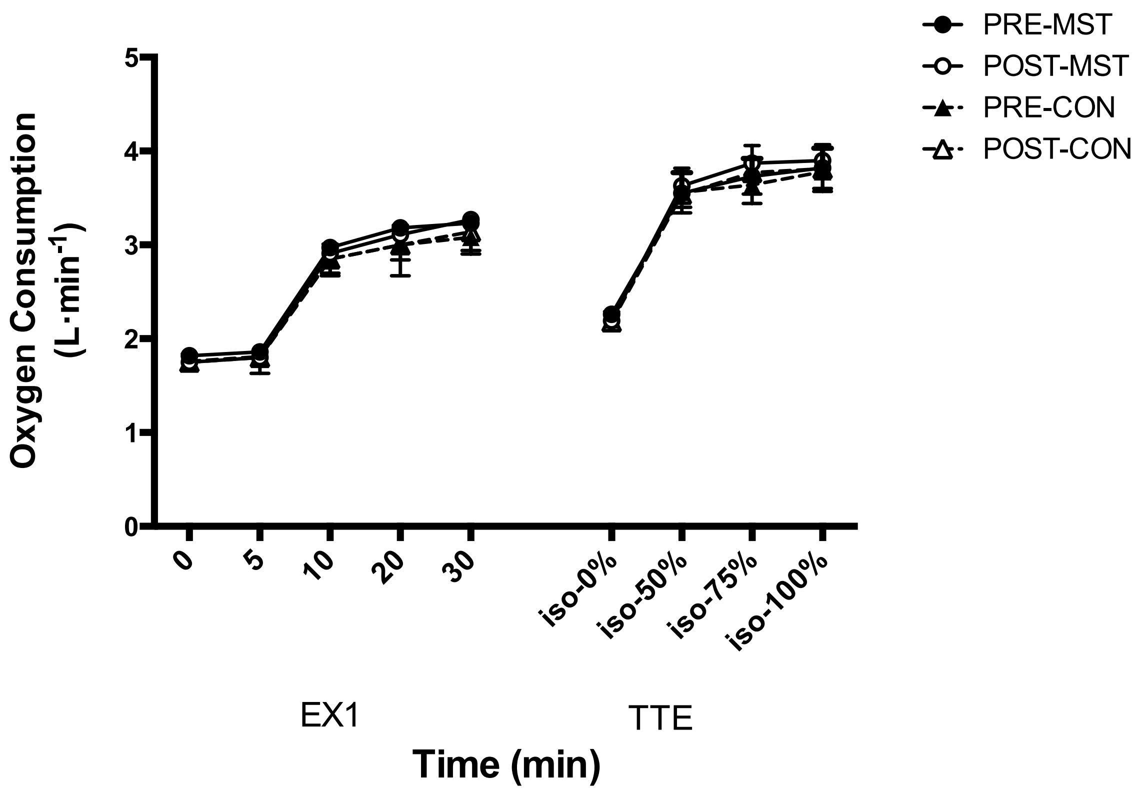

Figure 5-6- Oxygen consumption responses during PRE and POST trials. All data presented is mean (± SEM).

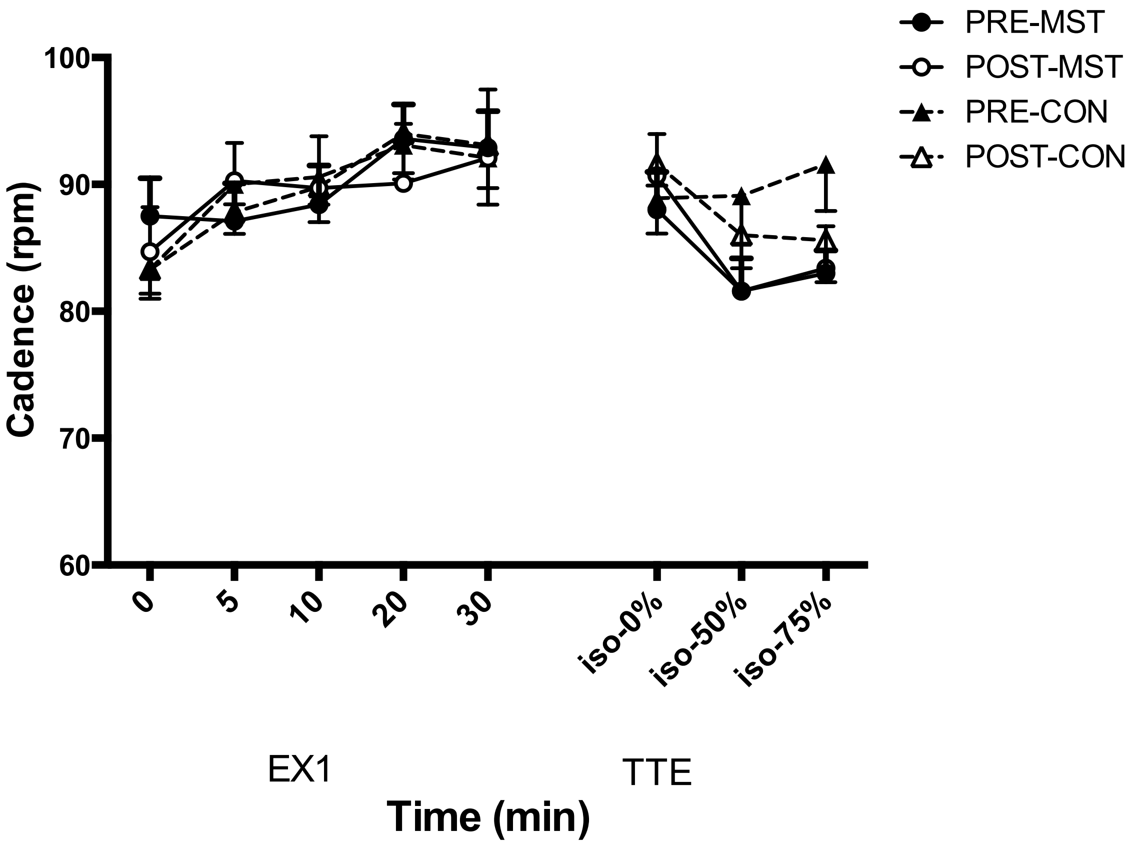

Figure 5-7- Cadence response during PRE and POST trials. All data presented is mean (± SEM).

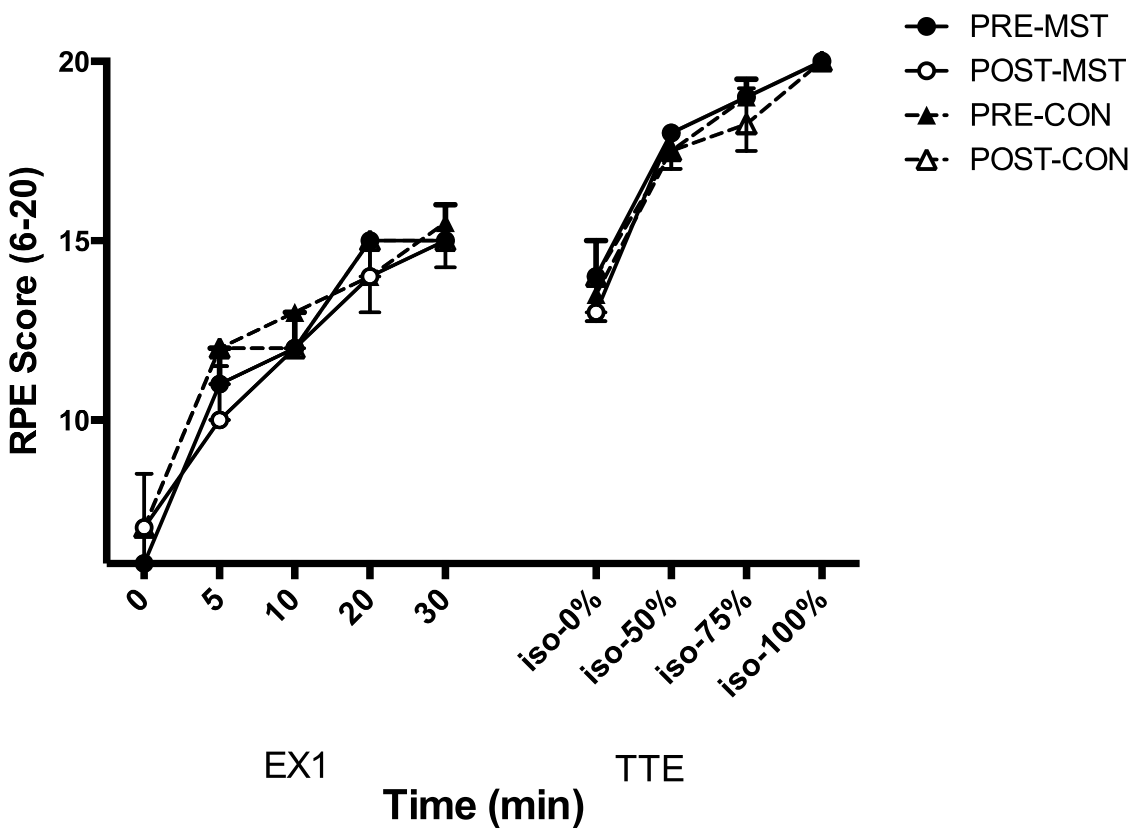

Figure 5-8- Perception of effort response during PRE and POST trials. All data presented is mean (± SEM).

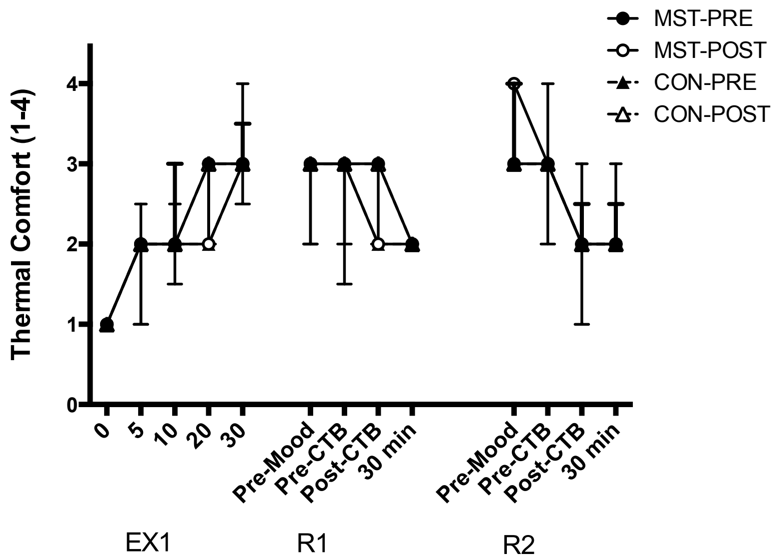

Figure 5-9- Thermal comfort response during PRE and POST trials. All data presented is mean (± SEM).

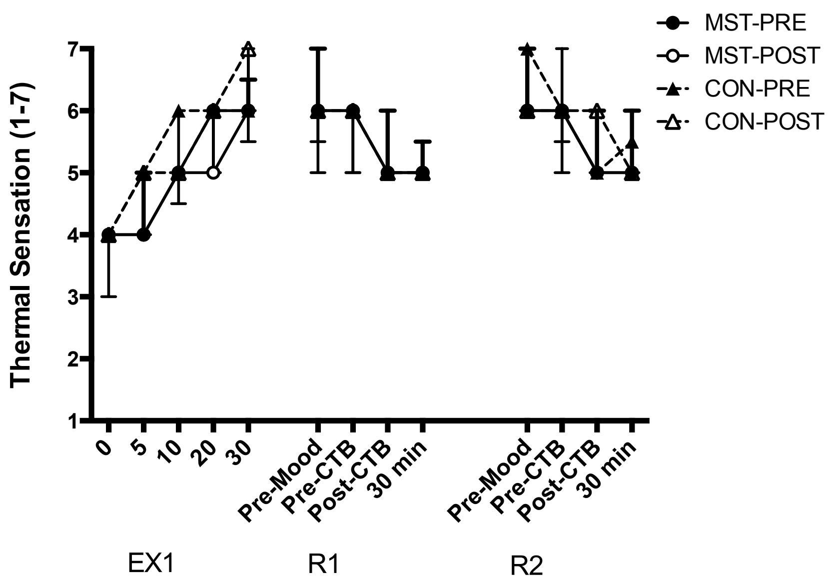

Figure 5-10- Thermal sensation response during PRE and POST trials. All data presented is mean (± SEM).

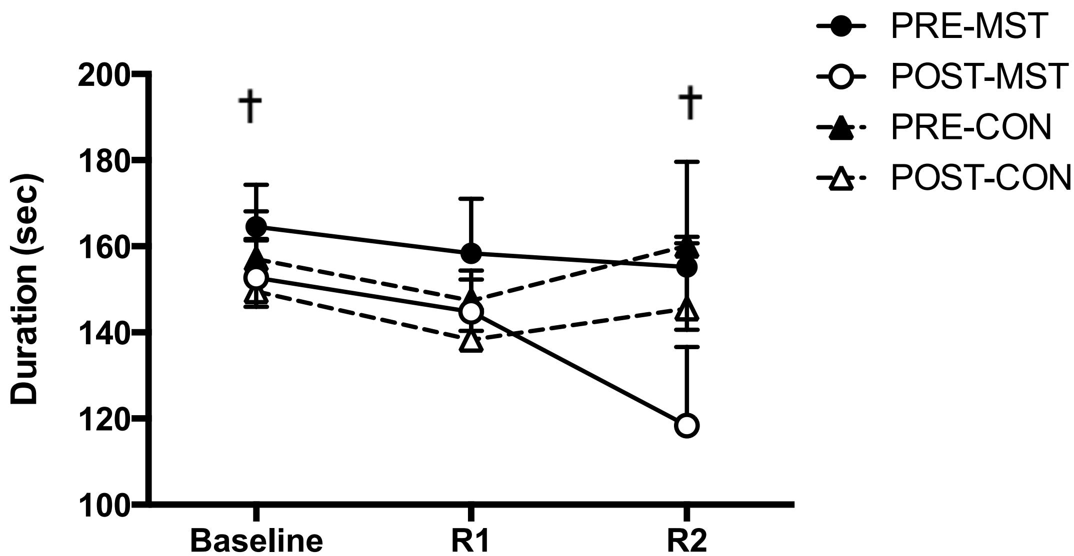

Figure 5-11 – Duration during the 5 block trials on the Groton Maze Learning Task. † indicates significant differences from PRE to POST in the MST group. All data presented is mean (± SEM).

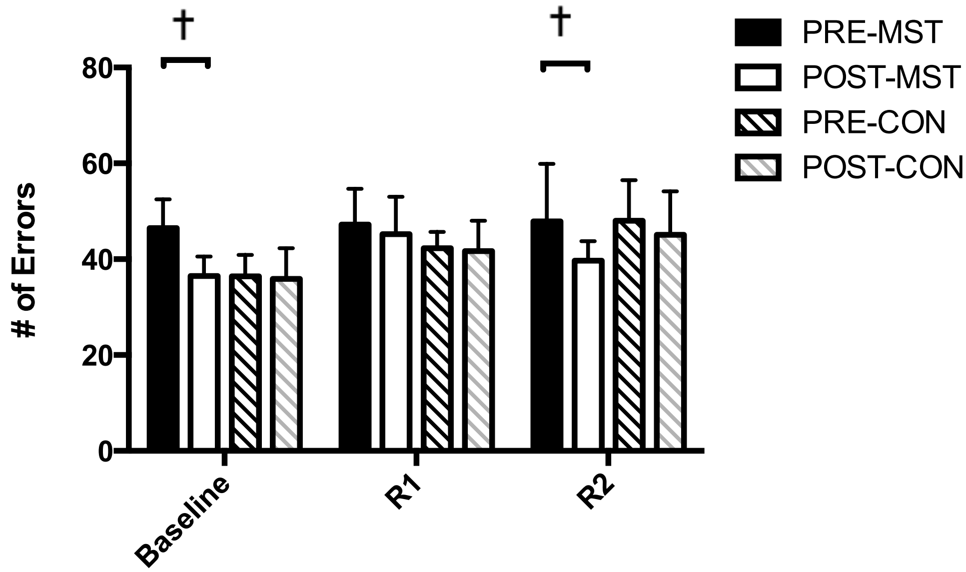

Figure 5-12 – Number of Errors Made during the 5 block trial on the Groton Maze Learning Task. ✝ indicates significant differences from PRE to POST in the MST group. There were no differences between MST and CON groups at any time point.

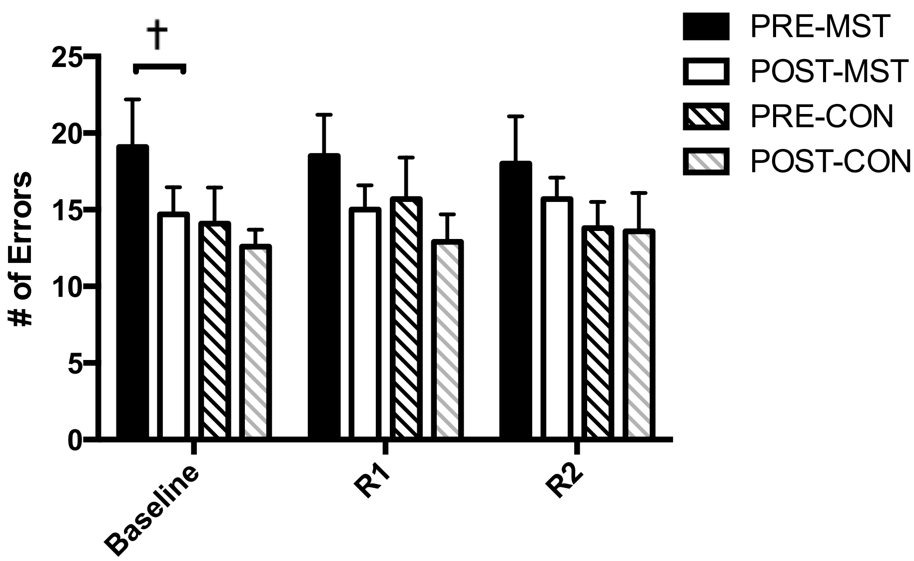

Figure 5-13- The # of errors made on the set shifting task. ✝ indicates significant difference from PRE to POST in MST group. All data presented is mean (± SEM). There were no differences between MST and CON groups at any time point.

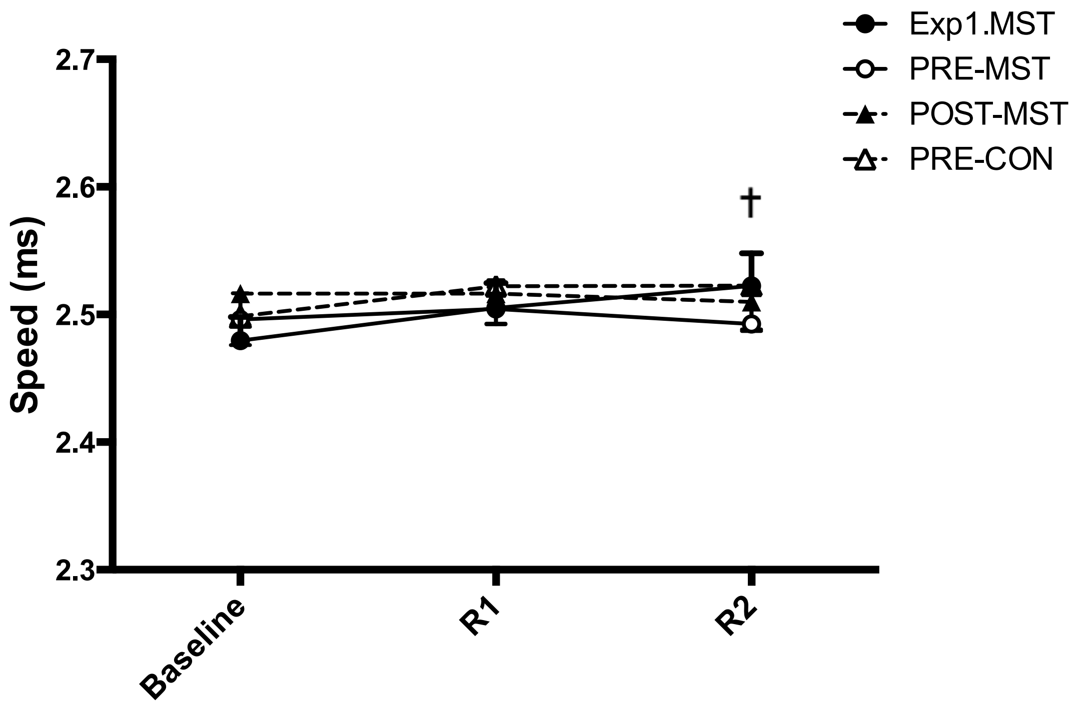

Figure 5-14- Reaction time speed on the detection task. † indicates significant difference from PRE to POST in MST group. All data presented is mean (± SEM). There were no differences between MST and CON groups at any time point.

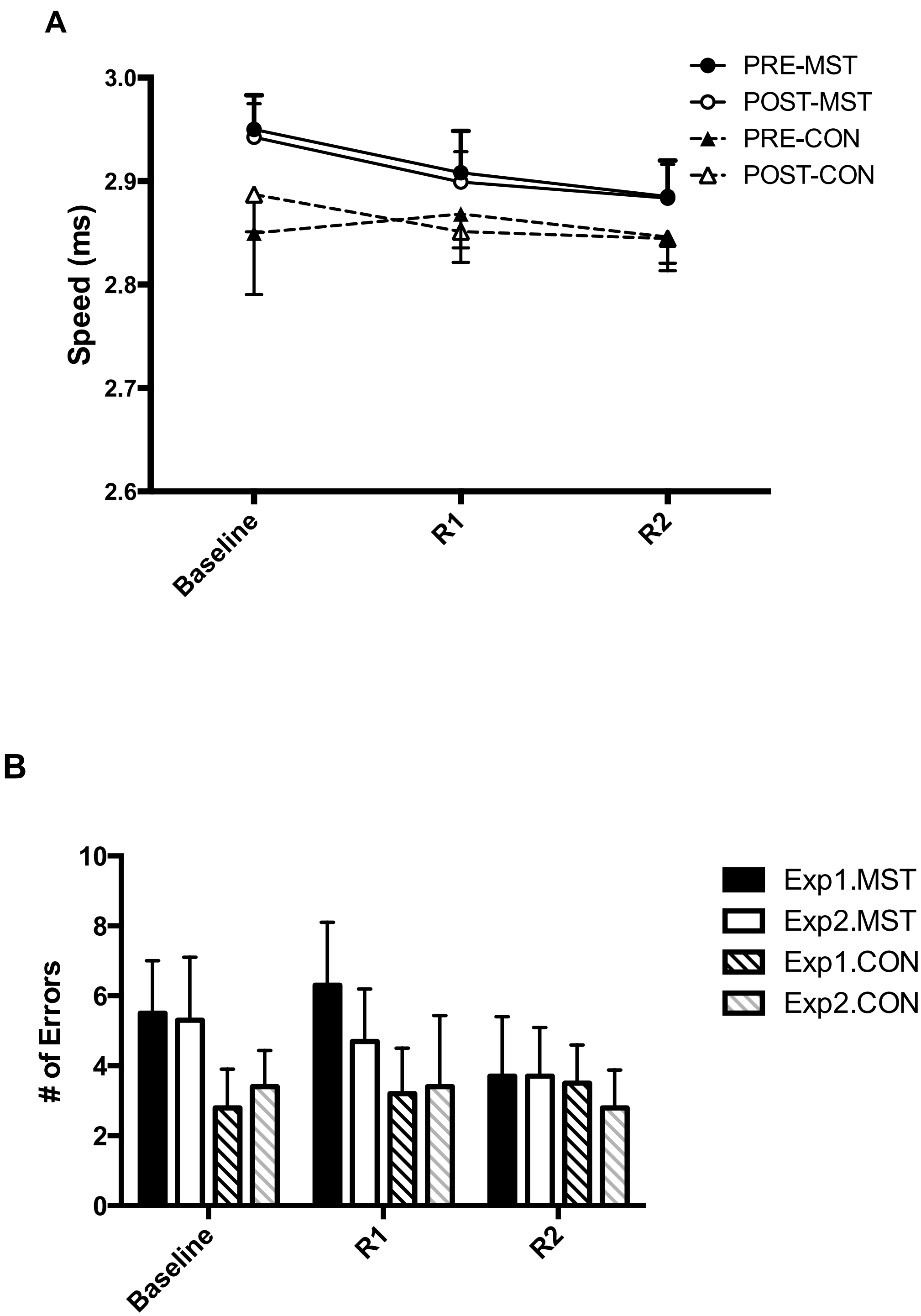

Figure 5-15 – Speed of processing (A) and # of errors made (B) during the two-back test. All data presented is mean (± SEM).

Cognitive Variable	Baseline		Rest 1		Rest 2	
	PRE	POST	PRE	POST	PRE	POST
GMLT- Trial 5 (speed (s))						
CON	21.6 (2.0)	18.4 (1.1)	19.3 (1.6)	19.5 (1.5)	19.7 (1.2)	17.5 (1.5)
MST	25.8 (2.8)	22.5 (2.6)	22.5 (2.5)	22.0 (2.9)	23.2 (2.1)	20.0 (1.4)
GMLT- Recall (speed (s))						
CON	23.4 (3.0)	19.5 (1.2)	23.0 (2.5)[a]	21.4 (2.1)	27.0 (5.2)	21.1 (2.6)
MST	24.7 (3.0)	21.5 (3.0)[†]	23.0 (2.2)	21.4 (2.2)	21.8 (1.9)	21.6 (2.5)
GMLT- Trial 5 (# of errors)						
CON	4.0 (0.9)	4.0 (1.4)	4.0 (1.4)	6.0 (1.7)	6.0 (1.8)	6.0 (1.3)
MST	6.0 (1.1)	5.0 (1.2)	6.0 (1.6)	5.0 (1.1)	7.0 (1.3)	5.0 (2)
GMLT- Recall (# of errors)						
CON	4.0 (3.2)	5.0 (1.2)	6.0 (1.6)[a]	6.0 (1.6)	8.0 (2.6)	7.0 (1.7)
MST	5.0 (1.8)	4.0 (0.9)	7 .0 (1.3)	6.0 (1.3)	6.0 (1.2)	7.0 (2.2)

Table 5-1- Completion speed and # of errors results from the GMLT-5 to GMLT-Recall from PRE to POST trials. [a] indicates significant difference between GMLT-5 and GMLT-Recall, † indicates significant changes PRE-POST in MST group only. All data presented is mean (SEM).

Mood Variable	Baseline		Rest 1		Rest 2	
	PRE	POST	PRE	POST	PRE	POST
Vigour						
CON	8 (7-9)	8 (4-9)#	5 (1-8)	6 (3-8)	4 (3-8)*	6 (3-9)*
MST	11 (5.5-12)	12 (7.5-12.5)#	6 (3-8)	8 (5-9)	2 (1.5-7.5)*	3 (2-3)*
Fatigue						
CON	2 (0-3)	0 (0-1)	3 (1-6)	4 (2-5)	6 (5-9)*	5 (1-7)*
MST	1 (0-2.5)	0 (0-0)	2 (1-6)	1 (1-2)	5 (3-10.5)*	6 (6-10)*
Tension						
CON	0 (1-3)	0 (0-2)	2 (2-3)	1 (0-2)	0 (0-2)	0 (0-1)
MST	0 (0-2.5)	0 (0-1.5)	1 (0-5)	0 (0-2)	0 (0-2)	0 (0-1)
Confusion						
CON	0 (0-0)	0 (0-0)	1 (1-2)	1 (0-2)	0 (1-2)	1 (1-2)
MST	0 (0-0)	0 (0-0)	1 (0-4.5)	0 (0-1)	0 (0-1.5)	0 (0-1)
Anger						
CON	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0.5)	0 (0-1)
MST	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-2.5)	1 (0-1.5)	1 (0-1)
Depression						
CON	0 (0-0)	0 (0-0)	1 (0-2)	1 (0-1)	1 (0-2)	1 (0-1)
MST	0 (0-0)	0 (0-0)	0 (0-2)	0 (0-1.5)	0 (0-3.5)	0 (0-3)

Table 5-2- Mood responses for both PRE and POST trials. Data is presented as Median (q1-q3). * indicates significant time effect ($p < 0.05$) from baseline. # indicates differences between MST and CON.

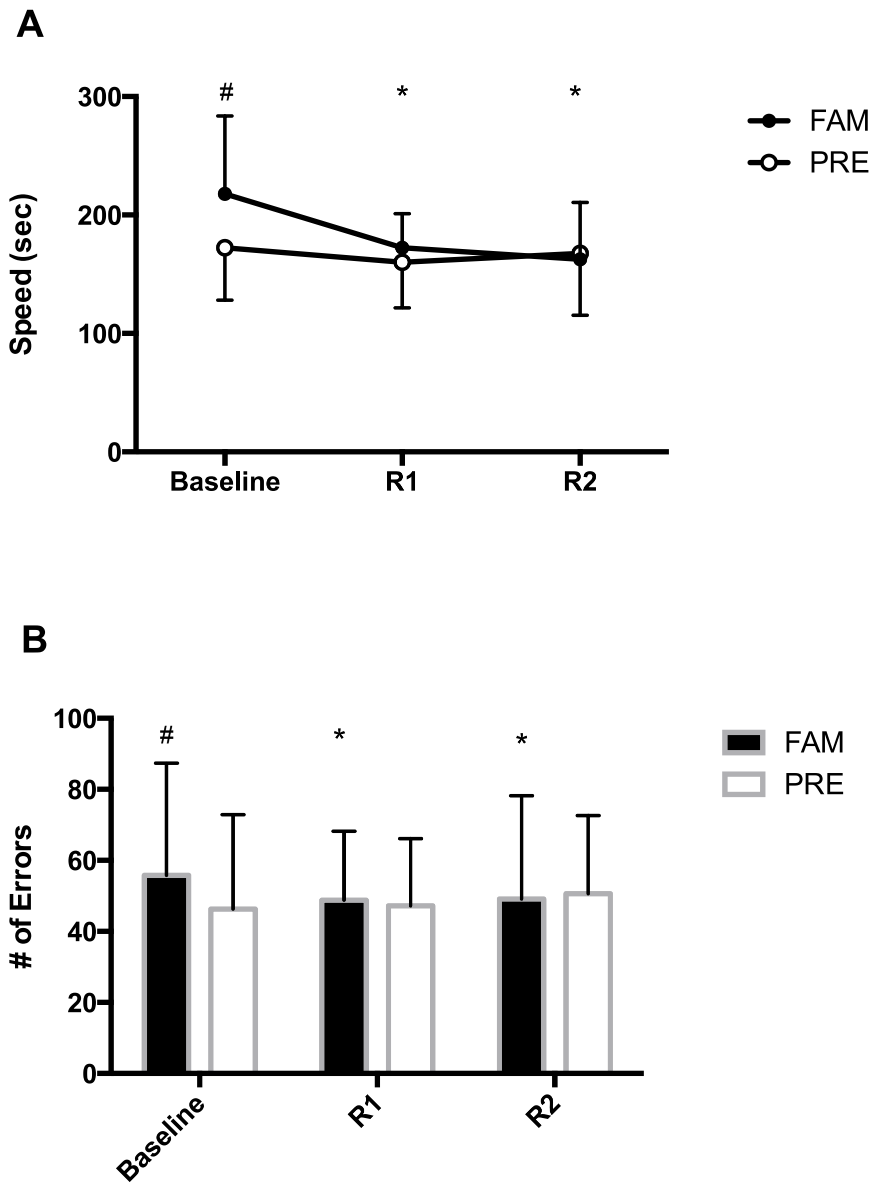

Figure 5-16 – Learning effect (*n* = 18) from FAM to PRE trial on GMLT-5 block trials. The figure contains learning duration (A) and # of errors made (B). All data presented is mean (± SD). * indicates time effect from baseline in FAM trial. # indicates significant difference at specific time-points from FAM to PRE trial.

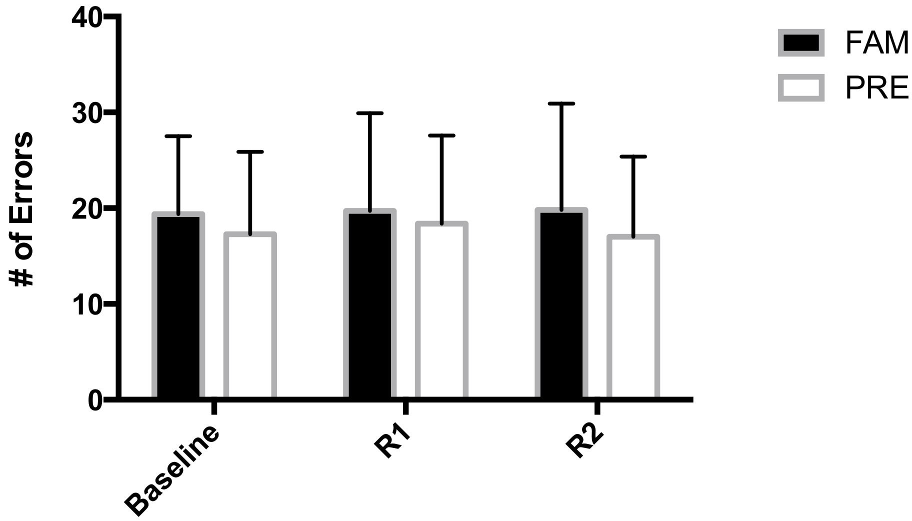

Figure 5-17 – Learning effect (*n* = 18) from FAM to PRE trial on the # of errors made on the set-shifting task. All data presented is mean (± SD).

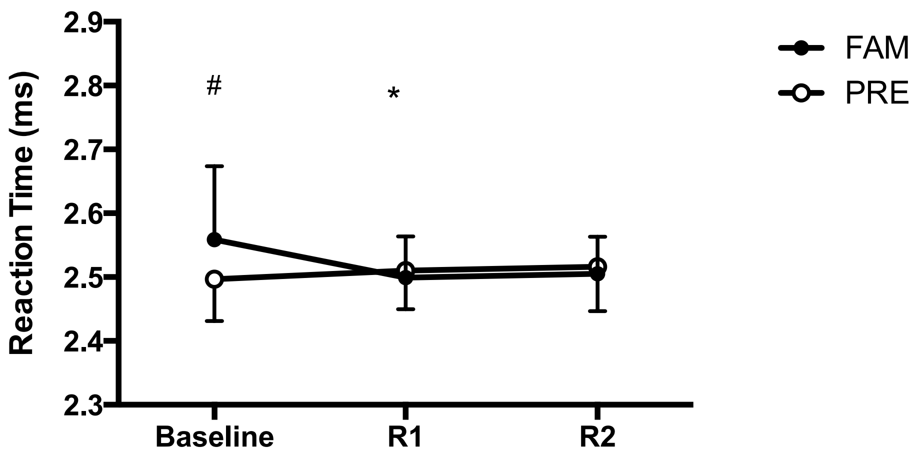

Figure 5-18 – Learning effect (*n* = 18) from FAM to PRE trial on reaction time during the detection task. All data presented is mean (± SD). * indicates time effect from baseline in FAM trial. # indicates significant difference at specific time-points from FAM to PRE trial.

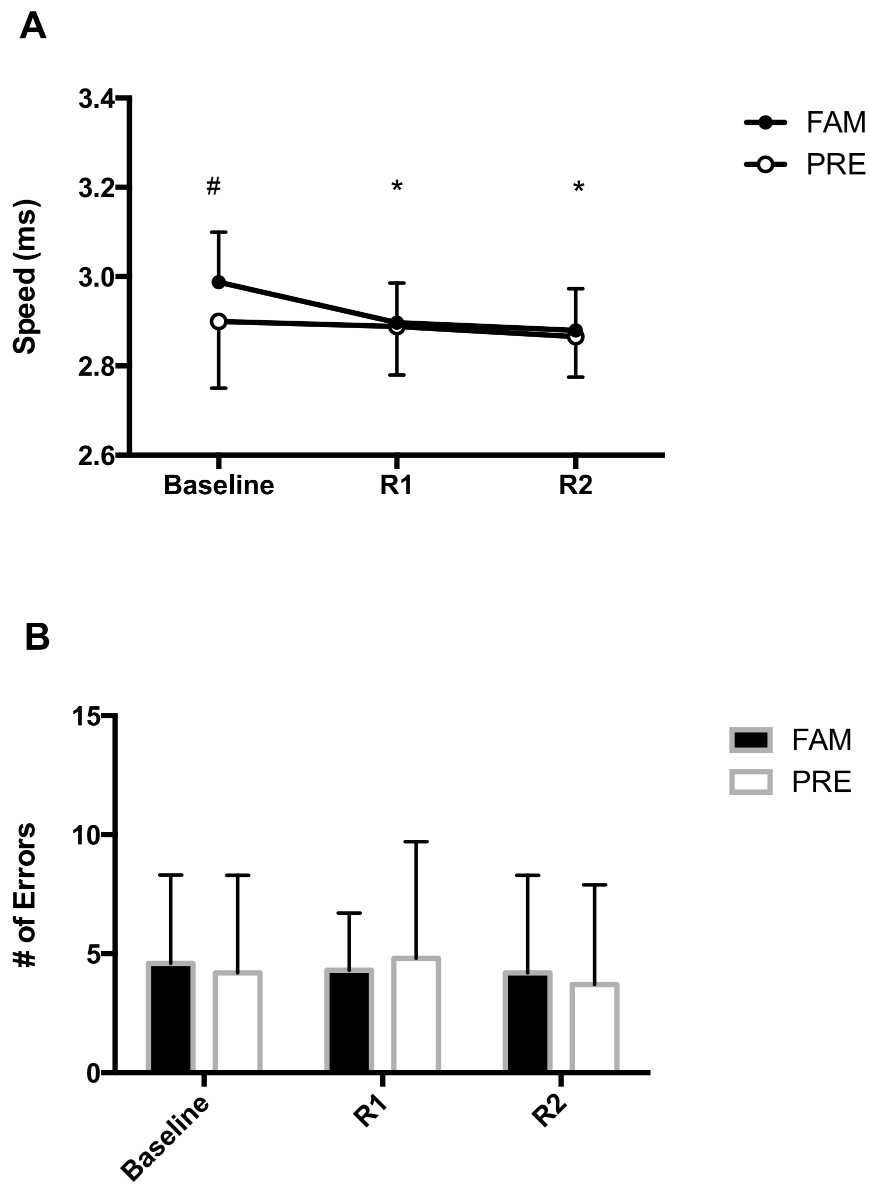

Figure 5-19 – Learning effect (n = 18) from FAM to PRE trial on two-back test. The figure contains speed of processing (A) and # of errors made (B). All data presented is mean (± SD). * indicates time effect from baseline in FAM trial. # indicates significant difference at specific time-points from FAM to PRE trial.

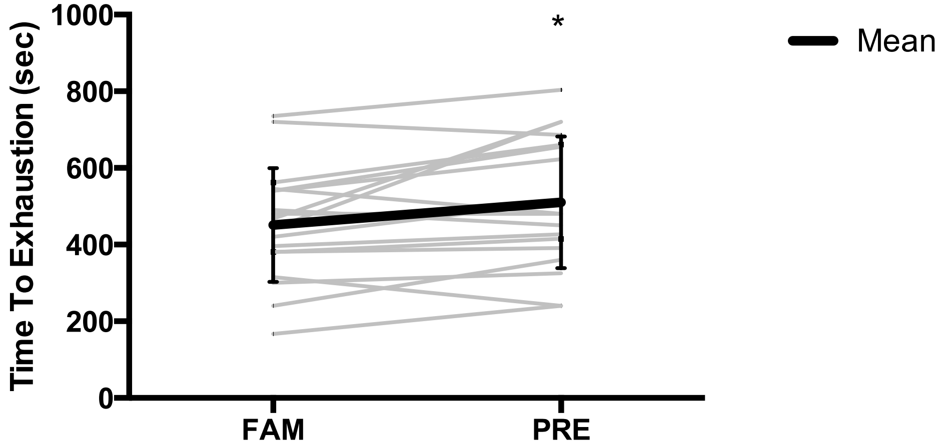

Figure 5-20 – Individual responses demonstrating the learning effect on the time to exhaustion test (*n* = 18) from FAM to PRE trials. * indicates significant difference from FAM to POST trial.

6 Discussion

Motivational self-talk is a top-down regulation strategy requiring participants to continuously re-appraise negative self-talk with self-contextualized motivational statements (Hardy, 2006). The intervention used in the current study was specifically designed to address endurance capacity and cognitive function in the heat. The primary finding was that MST led to a significant improvement in time to exhaustion by 30%, concurrent with a higher terminating core temperature. Additionally, MST improved both speed of processing and # of errors made for executive function tasks in both the thermoneutral and hot conditions. To our knowledge, this is the first study to quantify the use of a psychological skills training intervention to improve executive function in a thermoneutral or a hot environment. These findings demonstrate that the internal psychophysiological control of exercise and fatigue plays an important role in improving endurance capacity and higher order cognitive function in the heat.

6.1 Endurance Performance

The overall improvements in endurance capacity were not significantly related to any physiological variables measured, but rather an alteration in the internal psychophysiological control of behaviour and fatigue. Despite near maximal heart rate, ventilation, and oxygen consumption, the MST group was able to improve their TTE by continuously re-appraising the desire to voluntarily terminate exercise through specific self-contextualized statements. These findings suggest that participants were able to take advantage of a conscious feed-forward regulation of exercise using MST to improve tolerance time. This extends the previous evidence showing that MST is beneficial in improving endurance capacity (Blanchfield et al., 2014, McCormick et al., 2015) and gross motor tasks (Hatzigeorgiadis et al., 2004, Hatzigeorgiadis et al., 2011), as well as the beneficial use of psychological skill training intervention on exercise performance in the heat (Barwood et al., 2008).

Previous studies have shown that time to exhaustion performance is limited in the heat due to an attainment of a $T_c > 40°C$ (Gonzalez-Alonso, 1999), or decreased CNS arousal (Nielsen et al., 2001), and skeletal muscle recruitment (Tucker et al., 2004). It is unlikely in the current study that attainment of a high T_{re} was the limiting factor in TTE times, as termination T_{re} was lower than 40°C. Participants in the MST group finished with a significantly higher T_{re} in the POST trial. Based on the high workload from the task, the higher T_{re} may by due to the increased metabolic heat production from performing a longer bout of endurance exercise, or potentially the learned ability to tolerate a higher termination T_{re}. As increases in T_{re} are strongly correlated with declines in arousal in the frontal cortex ($r^2 = 0.98$) (Nielsen al., 2001), it would be interesting to test if MST led to a change in neurophysiological changes potentially through arousal in order to lead to performance increases despite a higher termination T_{re}. Additionally, there were no differences in cadence between trials so there were no behavioural associated changes during endurance tasks, suggesting that performance changes are likely due to central factors (Hartley et al., 2013). Future studies could look at central markers such as arousal to determine if there are measurable central changes that occur with high usage of MST.

The conscious perception of effort is derived from afferent input from the cardiorespiratory, metabolic, and musculoskeletal systems, as well as the affective appraisal of exercise (Ekkekakis, 2003, Crewe et al., 2008). It has been proposed that performance in endurance-based tasks is improved when interventions reduce an individual's sense of effort or perceived exertion during that task, while performance is reduced when perception of effort is increased (Marcora et al., 2009). Previous evidence has shown that MST led to a small but statistically significant reduction in RPE at 50% iso-time during a similar TTE test in thermoneutral conditions (Blanchfield et al., 2014). However, this same result is not found during any 1-km interval during self-paced 10 km time trials (Barwood et al, 2015). In the present study, RPE was similar between trials during EX1 and the TTE. Due to the constant load exercise used in the study, participants experienced the same level of bottom-up afferent feedback throughout the task (which is seen by the same physiological responses in both trials), which would lead to a similar level of perceived exertion. Combined with no differences in thermal perception or mood state, it is unlikely that psychological interventions can lead to a lower perceived exertion, but rather the learned ability to counteract the psychological context specific demands of the task (Hardy et al., 2001, Gammage et al., 2001) and environmental conditions (Barwood et al., 2006, Barwood et al., 2008). Therefore, the MST group learned to tolerate a higher discomfort throughout the later stages of the TTE in order increase endurance capacity.

Despite the significant improvements in endurance capacity with MST, it is difficult to determine the specific mechanisms for the change in performance, as there were no differences PRE to POST in any physiological, perceptual, and cadence measures. One component that illuminates an actual change to psychological strategies is the increased usage of self-talk. Overall the extent of self-talk usage during normal training sessions significantly increased over the course of the two-week practice period, as statements were practiced and re-phrased to self-contextualized MST statements. This evidence extends the findings from Barwood et al. (2008), which presented data showing an increased usage of psychological skill strategies in the post-intervention trial. Although in the current study, participants' pre-existing psychological strategies (e.g. imagery, dissociation) or awareness of self-talk strategies were not recorded pre-intervention, we can conclude that there was still a measurable change in MST usage. The practice of psychological skills during normal exercise training sessions may be a potential explanation on why studies employing a practice period consistently show improvements in performance (McCormick et al., 2015), while acute pre-exercise psychological manipulations such as attentional-based strategies, show inconsistent and variable influence over exercise performance (Lind et al., 2009). Overall, additional research is needed to determine the volume and dose-response relationship needed to determine and refine psychological interventions that will optimize performance in the heat.

6.1.1 Limitations

An experimental consideration of the study is the use of a TTE test to measure performance. Due to the constant power output, the test is less ecologically valid and more variable (26.6%) than a self-paced time-trial (Jeukendrup et al., 1996). Additionally there is an increased individual variability on TTE time with moderately aerobically fit individuals (McLellan et al., 1995). However, both TTE and time-trial tests are shown to have similar sensitivity to test performance (Amann et al., 2008). A full familiarization was given to participants to reduce the variability between trials (McLellan et al., 1995). Based on the consistent performance in the CON group between

PRE and POST trials, we can conclude that MST was effective at improving endurance capacity. Future research should look at the effects of MST on self-paced exercise and time-trial performance in the heat to determine if equivocal improvements can occur.

An experimental consideration of the study was not using a sham-control group in the study using an intervention such as neutral self-talk (Barwood et al., 2015). Experimenters spent more time with participants (~45 minutes longer), which may have improved performance due to the affect of social facilitation. Due to the study design, we cannot fully account for these potential confounding variables, however great effort was used to reduce social facilitation/ external motivation through no verbal feedback or encouragement during tests, use of same experimenters between trials, and no knowledge of results given between trials. Furthermore, Barwood et al. (2015) found that the use of a sham-control neutral self-talk and spending the same amount of time with participants does not influence cycling performance, while the MST intervention has a beneficial effect. Based on the similar responses found in the current study, and the high usage of self-talk in the MST group, it is likely the intervention led to performance increases. However, future research should use sham interventions in order to minimize any potential confounds.

6.2 Cognitive Function

Debate exists on whether or not exercise-induced hyperthermia affects cognitive function. Early studies show that exercise-induced hyperthermia results in a reduction in short-term memory, reaction time, and vigilance, however these studies often include additional stressors such as hypohydration and sleep deprivation (Cian et al., 2000, Cian et al., 2001, Lieberman et al., 2005). Recent studies have shown in isolation, there is an improvement in information processing, short-term memory, and executive function after light (Parker et al., 2013), and moderate (Zhang et al., 2014) exercise in the heat. Others have shown no declines in simple and complex memory tasks, reaction time, or psychometric vigilance when exercising to a core temperature of 39.5°C (Lee et al., 2014a, Lee et al., 2014b). In the current study, with exercise-induced hyperthermia after moderate and high intensity exercise in the heat, there were no performance decrements in reaction time, working memory, or executive function relative to thermoneutral conditions. Arguably, the thermal stress and exercise-induced hyperthermia of > 1.0°C may have been insufficient to perturb cognitive function. This response contrasts passive hyperthermia studies, which show task-dependent perturbations in cognitive function with rises in core temperature > 1.0°C (Pilcher et al., 2002, Hancock & Vasmatzidis, 2003). Conversely, the changes in cognitive performance seen with passive hyperthermia may occur due to the sensory displeasure of hot skin (Gaoua et al., 2012, Simmons et al., 2008), which competes and depletes available neural resources to complete cognitive tasks (Hocking et al., 2001). Additional research is needed to determine the effects of exercise-induced hyperthermia compared to passive hyperthermia on cognitive function.

In the current study, we used MST as an active re-appraisal strategy to counteract negative cognitions that may influence performance and minimize distractions from irrelevant environmental cues. Post-experiment questionnaires revealed that participants used MST during the cognitive test battery in order to maintain or increase both ‘focus’ and ‘concentration’ during the tasks, with no reported anxiolytic benefits, while the CON group used no psychological strategies. The MST intervention led to improvements in multiple measures of executive function including: visual planning and memory, conflict resolution and decision-making in thermoneutral before entering the heat as reflected by improvements on the GMLT and set-shifting task. There was also significant improvement in speed of processing and a reduction in errors made during the GMLT in R2 despite the 30% increase in TTE time. With passive hyperthermia by > 1.0°C, there is a neuronal shift in resources from the executive attention network, to the alerting and orienting attention networks (Sun et al., 2012, Liu et al., 2013). This neuronal shift in resources leads to decrements in executive function task performance, while simple cognitive task performance is maintained (Qian et al., 2014). Although we did not see decrements in executive function, due to the specific decrements and neuronal shift in resources that can occur with hyperthermia, interventions that can specifically improve executive function could be beneficial for athletes and workers performing in the heat. Overall, participants made significantly fewer errors on the GMLT and set-shifting task and performed the GMLT faster, demonstrating that MST is an effective modality to improve executive function and higher order cognitive functioning.

MST had minimal effects on simple cognitive tasks. There was no effect on working memory or speed of processing, while there was a significant improvement in reaction time during R2 in the POST trial. However, this is potentially due to heightened arousal from the significantly higher core temperature (Racinais et al., 2008), as opposed to the effect of MST per se. There may have also been no changes due to the task complexity of the task, as simple task are less vulnerable to hyperthermia compared to complex tasks (Pilcher et al., 2002, Hancock & Vasmatzidis, 2003) and performance decrements are measured once core temperature rises above 38.7°C (Racinais et al., 2008). Overall, these findings suggest that motivational self-talk potentially leads to task-dependent improvements in cognitive function, such that motivational self-talk improves executive function, but may have minimal to no performance changes on simple cognitive task performance in thermoneutral or hot environments. This contrasts other interventions such as cranial neck cooling (Lee et al., 2014a) and carbohydrate-electrolyte drinking (Lee et al., 2014b), which showed no improvement in cognitive function post exercise in the heat. Additionally, it does not appear that MST adds any additional cognitive loads, depletes attentional resources, or add to the global workspace based on no recorded declines on any of the cognitive measures in the POST trial (Gaoua, 2010).

A limitation of previous exercise-induced hyperthermia studies on cognitive function in the heat is that the cognitive tasks used were susceptible to a learning effect due to repeated exposure (Zhang et al., 2014), and core temperature dropped close to baseline by the end of cognitive testing (~ -2.0°C) (Lee et al., 2014a, Lee et al., 2014b). In the present study, a familiarization trial and randomized versions of each test were given that had identical levels of difficulty to minimize the learning effect in the PRE-POST trials. Furthermore, T_{re} was kept within ~0.1°C by the end of the CTB. Additionally, participants in both groups had similar aerobic fitness and worked at the same relative peak power output to minimize additional potential confounding variables (Gaoua, 2010). Therefore, the changes seen in cognitive function were due to a top-down regulation of performance through MST, as opposed to differences in thermoregulatory responses, aerobic fitness, or learning effects of performing the CTB.

6.3 Future Directions

The study of how psychological strategies and thermal perceptions affects performance in adverse environments is relatively new and there is still much to learn.

Based on the multiple measures and cross-functionality of this study, there are four key areas that need more research:

- Individual characteristics that affect the efficacy of motivational self-talk.
- Psychological interventions influence on exercise in different adverse environments (e.g. hypoxia).
- Occupational based studies (e.g. firefighter, underwater helicopter escape).
- The neurobiological mechanisms of use of motivational self-talk in the heat (e.g. neurotransmitters, substrates, and activation patterns).

Overall, testing these four key areas will both mechanistically determine how motivational self-talk works within in the brain and be able to determine practical applications to use with athletes, occupations, and military personal that have to work and perform in adverse environments.

6.4 Conclusion

In conclusion, MST had a beneficial affect on both endurance performance and executive function. Benefits of the intervention were seen through improvements in executive function at baseline before entering the heat. The benefits continued during performance leading to a significant increase in endurance capacity and executive function in R2. Despite the substantial increase in endurance capacity, there were no differences between PRE and POST trials in physiological, mood, or perceptual responses, however there was an increased use of motivational self-talk over the two-week practice period and subsequent higher usage in the POST trial in the MST group. Overall, these results indicate that using a top-down regulation strategy consisting of self-contextualized MST can improve physical and cognitive performance in the heat. Additional research is needed to determine the underlying neurobiological changes that led to this response.

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